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HARD FIBRES. *W. Bally and F. Tobler* 376

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The Search for Plant Precursors of Cortisone

The subterranean tubers of Mexican yams have superseded the seed of African Strophanthus vines as the most promising vegetable source of components commercially convertible into cortisone. This arthritis-combatting drug is still manufactured primarily from bile acids of cattle, but intense efforts are being made to find suitable plant sources. In this article four of the U. S. Government scientists engaged in this work describe what is being done in this direction under Federal auspices.

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Scope and Object 307
History: General and Biochemical 308
Exploration 313
Africa 316
Strophanthus 318
Mexico 318
Agave 320
Dioscorea 327
Central America 336
South America 340
West Indies 340
United States 340
Miscellaneous Regions 344
Horticulture 344
Treatment of Materials Received 346
Propagation 350
Greenhouse Culture 350
Tuber Storage 354
Harvesting and Shipping 354
Herbarium Specimens 354
Selection of Possible Ornamental Species 354
Field Testing and Evaluation 354
Strophanthus 357
Agave 360
Dioscorea 360
Savannah, Georgia 364
Brooksville, Florida 368
Coconut Grove, Florida 371
Baton Rouge, Louisiana 371
Texas 371
Puerto Rico 372
Conclusions Regarding *Dioscorea* 372
Bibliography 373

SCOPE AND OBJECT

Throughout this country and in many other parts of the world, the period following the end of the second world war has been one of great activity in the chemistry of natural products and the development of its applications. Botanists, chemists, pharmacologists and others have been interested in the chemical constituents of plants and their potential uses. Although, in some cases, it seems that the modern world is turning directly to remedies culled from ancient folklore, what is really happening is that a scientific basis for many ancient cures is being established, and, often, the application of the drug is being extended far beyond its original use; for example, *Rauvolfia serpentina* (L.) Benth., the Indian snake-root, from which reserpine is extracted and found to be useful for a variety of illnesses of modern man. There is great opportunity for cooperative effort by different fields of research, and the possible attainments are probably even now unimagined. Aside from the practical rewards in pharmacology and medicine, the gains in basic research are many. Relationships between plants linked to the chemical composition of their constituents are being recognized; new chemical compounds are being discovered; and horizons are being broadened for everyone concerned.

The Section of Plant Introduction, U. S. Department of Agriculture, is at present engaged in two major programs concerned with the investigation of wild

plants as possible sources for vital drugs. The oldest of these programs, originally a search for possible plant sources for the drug cortisone, was initiated by a presidential decree in 1950. This program was organized as a joint endeavor of two government agencies, The Department of Agriculture[1] and the National Institutes of Health.[2] The second program is also a cooperative one between these same two agencies[3] and has as its objective the procurement and testing of possible alkaloid-bearing plants in the hope of finding alkaloids useful in treating hypertension, or high-blood-pressure.

Only the first project dealing with our investigations of possible plant sources to produce the drug cortisone is discussed here. The ultimate objective of this program is to find and bring into cultivation plants that give the highest yield of the basic materials for the production of cortisone. If this were accomplished, a dependable supply of raw materials at relatively low cost would become available, and the dependence upon animal sources and erratic exploitation of wild plants would no longer be necessary. To accomplish this, field explorations in various parts of the world were initiated in 1949 to collect samples for chemical analysis of plant materials that were known to, or thought to, contain sapogenins. Where feasible, propagation stocks in the form of seed and vegetative material were prepared and forwarded with the sample for analysis. This living stock was propagated at our Glenn Dale, Maryland, U.S.D.A. Plant Introduction Garden[4], where it is being held or has, in the meantime, been distributed for growing under field tests. Through this activity we have built up a germ plasm collection of several hundred species, upon which we can draw, should the chemical results and agronomic appraisals warrant developing them as possible crops.

The difficulty of the task can readily be understood when its objective is considered in the light of traditional plant exploration and introduction. All previous plant exploration work by our Section has been undertaken primarily either to bring in breeding stock of already established agricultural crops for their improvement or to bring in plants being cultivated in other parts of the world for trial and possible establishment in the United States. This is not entirely true of some ornamentals, such as native species of *Rhododendron* from the Himalaya Mountains, which have been brought in directly from the wild for trial in this country. In the present work the main object has been to bring entirely wild species into acreage cultivation as soon as possible; in other words, to create and establish a completely new crop—a feat seldom accomplished in the annals of modern agriculture. It appears, nevertheless, from the data thus far obtained that, barring whimsical economic interference, such a new crop is on the threshold of becoming an actuality.

HISTORY, GENERAL AND BIOCHEMICAL

Much of the basic information contained in this section has been adapted from a paper published jointly by two

[1] Section of Plant Introduction (SPI), Horticultural Crops Research Branch (formerly Division of Plant Exploration and Introduction, Bureau of Plant Industry, Soils, and Agricultural Engineering), and Eastern Utilization Research Branch (EURB) (formerly Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry), Agricultural Research Service.

[2] National Institute of Arthritic and Metabolic Diseases, National Institutes of Health (NIH).

[3] National Heart Institute, National Institutes of Health and Section of Plant Introduction, Horticultural Crops Research Branch, Agricultural Research Service, Department of Agriculture.

[4] Future reference to this Introduction Garden will be merely "Glenn Dale".

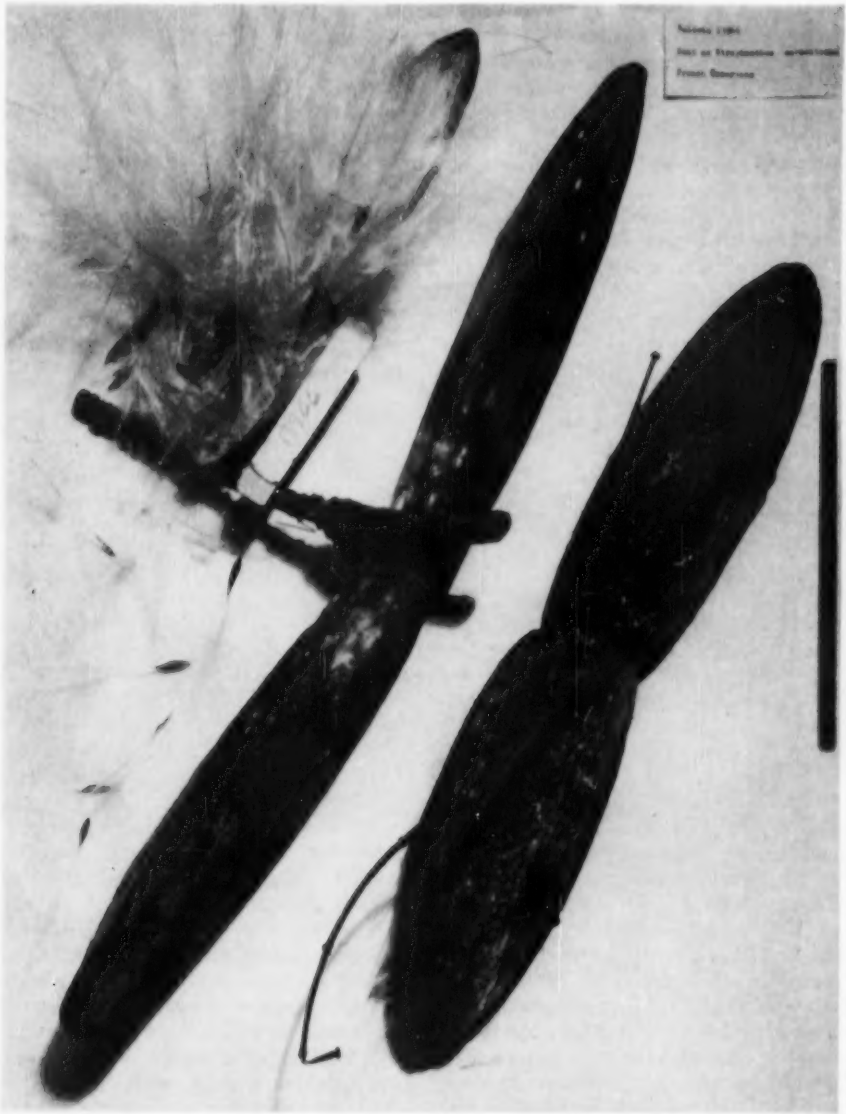


FIG. 1. *Strophanthus sarmentosus* DC. Fruits and plumed seeds, collected in French Cameroons by Baldwin, 1949. About $\times \frac{1}{4}$.

of the authors and some of the staff of EURB in the Journal of the American Pharmaceutical Association (27).

Cortisone was originally isolated from the adrenal cortex. Its commercial development was based on synthesis from bile acids, and these are still the principal source. Even though recent improvement of methods of extraction has resulted in a much greater production of cortisone from this source than that originally obtained, the supply of these acids is naturally limited by the number of cattle slaughtered. A cheaper and potentially unlimited plant source of a suitable raw material for the production of this and other therapeutic agents would obviously be of inestimable value. Since 1948, academic, industrial and governmental research agencies have endeavored to find new and improved starting materials for cortisone. Recently diosgenin, from Mexican dioscoreas, has come into use.

Although the historical background leading up to the demonstration, in 1948, by Drs. Edward C. Kendall and Philip S. Hench, of the Mayo Clinic, of the dramatic effect of cortisone in the treatment of rheumatoid arthritis has been published many times, a brief summary is in order here.

Kendall, a specialist in hormone chemistry who first isolated thyroxine, the hormone of the thyroid gland, in 1914, had by 1935 succeeded in identifying six different substances, including Compound E, or cortisone, from the adrenal gland. This was to prove to be the "Substance X", predicted by Kendall's colleague, Hench, to be a compound specific in nature and function that would stimulate dormant corrective forces he believed to be within every rheumatoid arthritic. The joint physiological studies of the above men were made possible by Dr. L. H. Sarett, of Merck and Company, who, in 1944, discovered how to synthesize cortisone from bile acids, and had so improved the process that several grams were available for testing purposes.

Another contemporary investigator who independently identified the chemical structure of cortisone was Tadeus Reichstein of the University of Basel, Switzerland. A large portion of the basic work contributing to the final discovery of cortisone and its synthesis by Sarett was accomplished by Reichstein and his assistants in Switzerland.

Since the yields from bile acid synthesis were low, it was obvious that only a plant source could provide a cheap and potentially unlimited supply of suitable cortisone precursors. Among the plant compounds first given serious consideration were sarmentogenin, stigmasterol, ergosterol and several of the steroidal sapogenins.

As early as 1929, seeds of an African species of the genus *Strophanthus*, presumably *S. sarmentosus* DC. (Fig. 1), were reported as containing sarmentogenin. Since sarmentogenin has an 11-hydroxyl group, it is potentially a much better cortisone precursor than bile acids. Staff members of NIH, in following up this potential plant source for cortisone, requested the cooperation of the Bureau of Plant Industry, Soils, and Agricultural Engineering in obtaining raw materials of this genus and, in July, 1949, transferred sufficient funds to the Division of Plant Exploration and Introduction (now SPI) to support an expedition in West Africa to search for materials of *Strophanthus* species. John T. Baldwin, Jr., of the College of William and Mary, was employed to do this exploratory work.

"From the pioneering researches of R. F. Marker and his associates . . . it was known that steroidal sapogenins are readily converted to pregnane compounds with the desirable hormonal side chain. At first only steroids in which the 11-oxygen could be introduced

chemically were useful. These included hecogenin with a 12-carbonyl group and diosgenin with unsaturation between carbons 5 and 6 . . . . More recently it has been shown that progesterone can be converted microbiologically to 11-a-hydroxy progesterone . . . . Hence all progesterone precursors are potentially valuable. Among the steroidal sapogenins, diosgenin is outstanding but sarsasapogenin, smilagenin, and tigogenin can all be used for progesterone synthesis. Sapogenins with hydroxyl groups in positions other than carbon 3 and with 12-carbonyl groups are less satisfactory for this purpose" (27).

Marker and associates found that these sapogenins occur most frequently in plant families in the order Liliales. The several families that have proved to be of greatest interest are Amaryllidaceae, which includes *Agave*, the source of hecogenin; Dioscoreaceae, including primarily the genus *Dioscorea*, the source of diosgenin; and Liliaceae, including (among many other genera) *Yucca*, the source of other sapogenins. It was thus fortunate that Marker's fundamental research served as a preliminary guide as to what to look for and where to look for it.

Following conferences of representatives of NIH, SPI and EURB, it was decided that the combined forces of the three agencies could make an important contribution to the problem of increasing the cortisone supply. With authorization and funds from Congress in the fall of 1950, the three agencies initiated their program: SPI to procure raw plant materials for chemical analysis and to try to develop promising species as crops; EURB to isolate and chemically study potential cortisone precursors in the plant materials procured; NIH to synthesize cortisone from suitable plant

FIG. 2. *Yucca arizonica* McKelv., left, and *Lemaireocereus thurberi* (Engelm.) B. & R., right, in northwestern Sonora, Mexico.

steroids isolated by EURB. Also, NIH was to continue research on *Strophanthus* as originally begun in July, 1949.

In the plant procurement phase, Gentry started exploration in Mexico and southwestern United States in September, 1950, and has continued to some degree ever since. Other collectors who worked with Gentry in Mexico are E. C. Ogden, New York State Botanist, formerly of the University of Maine; the late W. B. Fox, of North Carolina State College; and C. L. Gilly, formerly of Michigan State University. In addition, Oliver W. Norvell, Carnegie Institution of Washington, explored in Central America. In the meantime, several collaborators obtained materials from various regions in the United States. The principal ones were Robert R. Cruse, Tucson, Arizona; R. K. Godfrey, Florida State University at Tallahassee, formerly with North Carolina State College; W. H. Duncan, University of Georgia; Barton H. Warnock, Sul Ross State Teachers College, Alpine, Texas; C. F. Reed, Baltimore Junior College. Walter H. Hodge, now with SPI, was sent to southern Africa, January to June, 1951.

Because of their increasing importance, emphasis was placed on collecting *Agave* and *Dioscorea*. This continues in the hope that even higher yielding species or strains may be obtained for the purpose of making them into agricultural crops as soon as possible. In order to avoid overlooking some other part of the plant kingdom that might give rich yields of sapogenins, plant materials from diverse families outside the Liliales are being chemically tested. These plant samples are not only acquired from nature but are being taken from a rich reservoir of living plant materials maintained at the various plant introduction gardens of SPI.

Up to the present time, 5,320 plant samples, representing 1068 genera in 219 plant families, have been secured for chemical analysis in this program. Among these are collections of *Dioscorea* giving as much as 8.5 and 10.1% diosgenin, the two highest yields on record, and an agave giving as much as 2.5% hecogenin and another 3.6% total sapogenins. Besides these two genera we also have under cultivation a collection of *Strophanthus* giving 1.2% sarmentogenin, the highest yet obtained anywhere. All of these sapogenins are basic precursors for production of the drug cortisone, as well as of the sex hormones.

In addition to analyzing the plant collections for steroidal sapogenins, the chemists are also examining them qualitatively for four other groups of constituents—flavonols, alkaloids, tannins, sterols. The results have been tabulated and are being reported for each 1000 collections (27, 28, 31, 32). The findings thus far in this miscellaneous assortment have been profitably utilized by several private and governmental agencies, and, in the case of tannins, analyses are being made of those plants that give favorable qualitative tests (5).

EXPLORATION

This section has been written largely from the viewpoint and experience of the active field botanist who, because of the rapidly changing demands of the program, often became confused or disoriented with unpredictable chemical results and what appeared to be erratic objectives. It must be explained in defense of the stay-at-homes, however, that in the early stages of the work, discoveries in steroidal structures and improved chemical techniques were developing fast and necessitated rapid

FIG. 3 *Dioscorea elephantipes* (L'Hérit.) Engl. Hodge examining a large old "elephant foot" in eastern Cape Province, South Africa; note young plant at lower right, 1951. (Photo: W. H. Hodge).

decisions as to where the emphasis should be placed in plant collecting.

The field exploration for sapogenous plants has ranged over large areas of the world. In addition to receiving the help of many cooperating institutions and individuals, our Section has employed, for varying lengths of time, the services of eight botanists as plant explorers in the cortisone project. During the past five and one-half years, from 1949 to 1955, they have assiduously searched for wild plants in North and Central America, and to some extent in Africa, South America and India. These field investigations, beginning with emphasis on *Strophanthus* in the Apocynaceae, shifted, according to chemical findings and needs, to *Dioscorea* in the family Dioscoreaceae, *Agave* in the Amaryllidaceae, and *Yucca* in the Liliaceae. At present the primary interest is centered in *Dioscorea*. Along the way other genera, such as *Veratrum* and *Trillium*, aroused momentary interest, only to be dropped for one reason or another.

As the plant samples accumulated, with resulting chemical analyses, the general orientation within these plant families became more confused instead of clarified because of the elusive nature of plant steroids. The same species at different localities and even the same individual plant yielded varying amounts or, in some cases, entirely different sapogenins, according to the time of sampling or age of the plant. For instance, repeat collections of a plant that showed a relatively high sapogenin content when first collected would frequently give a negative or totally different result when analyzed the second time. To the conscientious field man this was extremely discouraging. It was early realized that, at least in some *Yucca* species, there existed a direct ratio between the season and the steroidal content of a plant. Although this has not been entirely proved with respect to *Agave* and *Dioscorea*, it is strongly suspected that such might also be the case in these genera. In *Yucca peninsularis* McKelvey and *Y. gloriosa* L. the highest steroidal content was found in samples taken at the time of maturation of the inflorescence.

To complicate matters further, in the beginning phases of the program it was not definitely known which of the many kinds of plant sapogenins would eventually prove to be the most practicable, industrially and agriculturally, as precursors of cortisone. Consequently, the chemical needs vacillated at intervals from *Strophanthus* to *Yucca* to *Agave* to *Dioscorea*, and back again. This led to frequent changes of emphasis, not only on plant groups but also on widely separated geographic regions. For instance, a field man following a pattern of exploration in southwestern United States and Baja California, looking for *Agave* and *Yucca* (Fig. 2) in these semi-arid regions, would suddenly find himself requested to go posthaste to the flooded steamy jungles of southern Veracruz to ferret out the *Dioscorea* species growing in almost impenetrable thickets. It takes a well-balanced resourceful field man to maintain a high morale under such circumstances.

Ingenuity has had to be displayed constantly in packaging and transporting the plants as well as in collecting them. All types of transportation have been utilized—man-back, mule, boat and airplane as well as ordinary automobile and railway express. Much of the material from remote places in Africa and South America has had to be transported by air freight. Many agencies have given their unstinted cooperation to expedite the shipments.

As noted previously, although a large general collection has been made, the main emphasis has been on the assembling of *Strophanthus*, *Agave* and *Dioscorea* species. The miscellaneous collections either were made incidentally on

FIG. 4. *Dioscorea montana* (E. & Z.) Spreng. Rhizome collected near Roossenekal, Transvaal, South Africa; about 3 dm. long. (Photo: H. King).

expeditions for these three genera or were obtained otherwise by special effort. The work of the various expeditions is discussed here by regions.

Africa

Two expeditions have been sent to Africa in search of plants of potential value in the production of cortisone. The first of these, which was incidentally the first expedition in this program, was made by J. T. Baldwin, Jr., from July, 1949, to June, 1950, primarily in search of species of *Strophanthus*. The second excursion was by W. H. Hodge from December, 1950, to June, 1951, mainly to obtain bulbous, cormo e or tuberous species of Liliaceae, Amaryllidaceae, Iridaceae and Dioscoreaceae—species whose vegetative storage organs might be possible sources of steroids—as well as any additional kinds of *Strophanthus* that might be located.

As noted previously, *Strophanthus* gave the initial impetus to the work that eventually resulted in this program. It is a genus of tropical plants whose species have long been known for their pharmaceutical and poisonous properties. The first seeds of *Strophanthus* known to have been planted in this country by the United States Department of Agriculture were introduced in 1914 by a pharmaceutical firm.

It was for these plants that Baldwin explored West Africa for nearly a year (1949–1950). His travels took him from Liberia to Ivory Coast, Gold Coast, Togo, Dahomey, Nigeria and the Cameroons. Through his endeavors about 55 samples of seeds and vegetative parts of many species were obtained for chemical analysis. He also obtained about 30 collections for propagation. In addition, Baldwin collected several large lots of *Dioscorea* tubers for chemical analysis.

The work of the second expedition to Africa, undertaken by Hodge in 1950–1951, was concentrated largely in South Africa, especially the Cape Province. This region is one of the greatest centers of species of bulbous lilies and amaryllids known in the world, many of which are now important in horticulture under the name of "Cape bulbs". Additional areas explored included eastern and northern Transvaal, the Rhodesias, Swaziland, Namaqualand and Natal.

Unfortunately, Hodge's expedition had to be undertaken at a poor season. He was compelled to seek out and collect bulbous plants that were already dormant, an extremely trying task. As a result, a great number of endemic bulbous genera and species that in optimum season would have been secured were completely missed.

Most South African bulbous plants are spring-flowering, and, since there are two diametrically opposite seasons obtaining in the Union, and therefore two "spring" seasons, a decision had to be made on a starting point. Except for a small area on the south coast where rainfall is more or less constant throughout the year, most of the Union readily divides into: *a*) a region of summer (December–February) rainfall, which includes the greater part of the country as well as the neighboring areas of Southern Rhodesia and Northern Rhodesia; *b*) a region of winter (June–August) rainfall, which covers a comparatively narrow strip of country at the southwestern extremity of the Union, centering in Capetown. Generally speaking, the greater proportion of bulbous species break dormancy and flower at the beginning of the rains; in fact, a number of species or genera can be located only at this time. From this it can be easily seen that the period July–December, inclusive, is the very best time for the collection of bulbous plants in South Africa.

Upon his arrival in the Union of South Africa in early January, it was evident to Hodge that the only chance of locat-

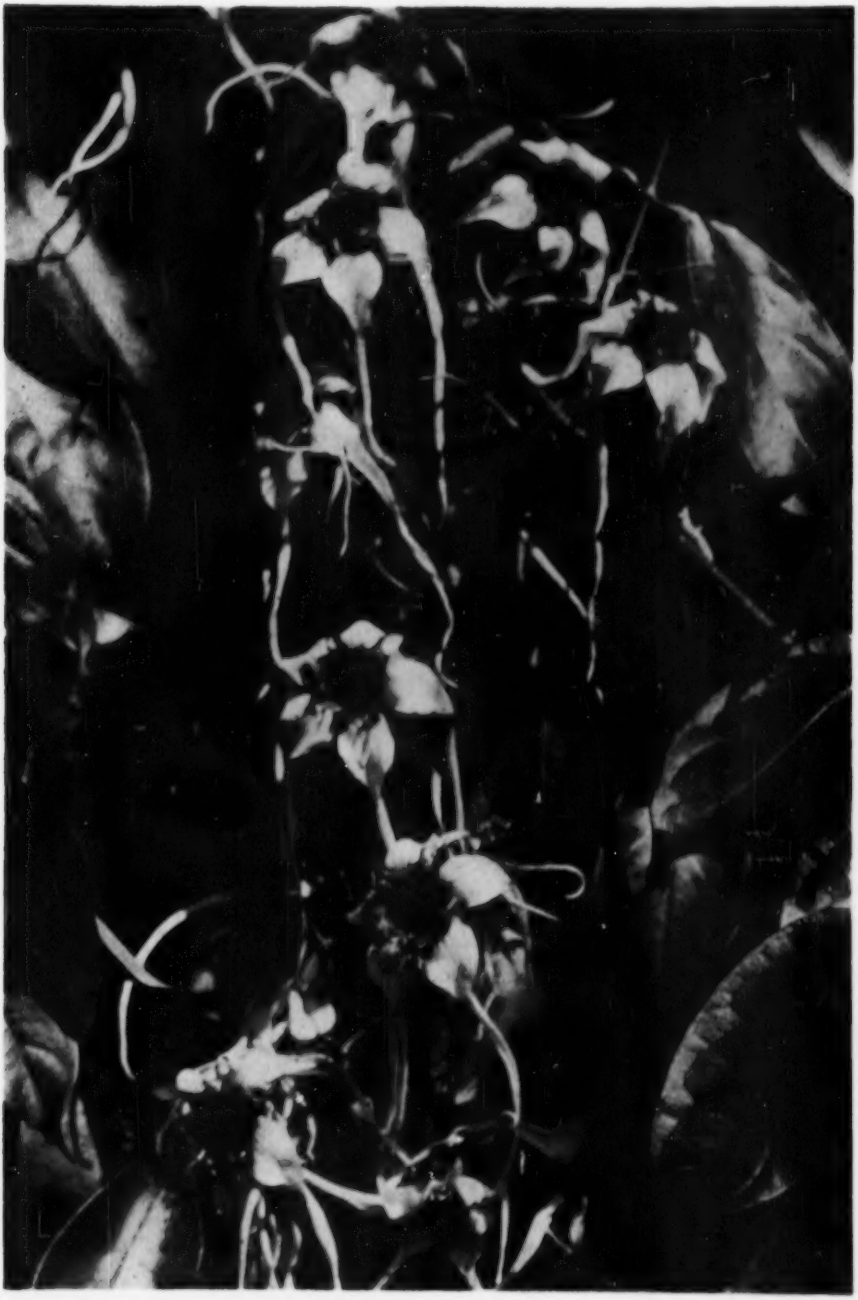


FIG. 5. *Strophanthus sarmentosus* DC. Flowering plant; note long caudate petals.

ing bulbous species in the southwest Cape Province would be immediately, provided that the plants had not already become dormant. Accordingly, a tentative itinerary for the period, January through June, in southern Africa was planned. This was to begin with collecting in the southwesterly part of the Union, then to move up the wetter east coast along the Indian Ocean and from there to turn inland into the Transvaal and the Rhodesias, reaching the northernmost part of the planned exploration area at Lake Tanganyika before the termination of the summer rains in late April. Because of the lack of time, the arid and relatively bulb-poor areas of Southwest Africa and Bechuanaland and the neighboring parts of the Union, originally tentatively included in his itinerary, were omitted.

Although it was not the best collecting time, Hodge was successful in obtaining a number of species in 11 genera of Amaryllidaceae, 13 of Liliaceae, and three of the Iridaceae, as well as several species of *Strophanthus* and *Dioscorea* (Figs. 3 and 4). Among these collections were a new species and several new introductions that promise to be excellent ornamentals for southern California —worthwhile by-products of his foray for "cortisone" plants.

In August, 1952, 14 collections of *Dioscorea* were sent through the cooperation of Temple Clayton, formerly of Schering Corporation, by Scherag, their South African subsidiary. These collections were propagated and are still being maintained.

In the summer of 1952, also, R. K. Godfrey, on an expedition for SPI, chiefly for forage plants, sent selected samples of Amaryllidaceae for this program from South Africa.

Strophanthus. Since *Strophanthus* was initially so important, and because all the collections of it were made in Africa, it seems fitting at least to mention the genus at this point. The species may be vines, shrubs or trees, and are distributed in tropical Africa, southern Asia, Malaya and the Philippines. Most of those in West Africa are vines that climb to the tops of trees when growing in the shade and form scandent shrubs when growing in the open. Many of the species are spectacular in full bloom (Fig. 5). The funnel-shaped flowers are usually white or pale cream and have a deep purple throat. The petals of most terminate in long streamers. The seeds, somewhat larger and flatter than wheat grains, are covered with appressed silky hairs and have a hairy tuft at the end. They are borne in pairs of pods, 12 to 14 inches or more long.

For centuries natives of Africa have used species of *Strophanthus* as a source of poison for spears and arrows; hence its common name, "poison-arrow" plant. The poison was obtained by pounding the seeds into an oily mass which produces a red color. Small portions of this were applied immediately behind the barb.

Under the name "Semina strophanti", the dried ripe seeds, freed from hairs, are official in the British and many other pharmacopeias. As ordinarily administered, the drug acts as a heart stimulant.

Over 50 collections of *Strophanthus* for chemical testing were made during the period when interest in the genus was at its peak (6). Portions of almost all these collections were also propagated and increased at Glenn Dale. Cultural experiments are still being continued at Mayaguez, Puerto Rico.

Mexico

Our major goal in the exploration of Mexico was to obtain as many species as possible of the highly important genera *Agave* and *Dioscorea*. Discussion of the Mexican field work will thus be divided into two phases—that for *Agave* in the arid and semi-arid regions rang-

FIG. 6 (Upper). Gentry with a severed inflorescence of *Agave gracilipes* Trel. in west Texas, 1950. (Photo: E. C. Ogden).

FIG. 7 (Lower). Ogden with plant sample of *Agave gracilipes* Trel. in west Texas, 1950.

ing from Baja California to the "Puebla Desert" of the central interior; that for *Dioscorea* chiefly in the subtropical and tropical regions, with rainfall above 25 inches annual average. The latter genus is more common at lower elevations, but a few species have been found at elevations around 8000 feet.

Within their respective climatic regions, both *Agave* and *Dioscorea* are xerophytic genera or essentially so. They have special organs or tissues which conserve moisture and nutrients and thus enable the plants to survive drought periods of a season or even of years. In *Dioscorea* the conserving tissue is composed of rhizomes, tubers, tuberous roots or swollen root crowns that enable the plants to meet severe competition and the tropical winter-spring dry season. The swollen meristem and enlarged parenchyma of *Agave*, together with its large succulent leaves protected by a cutinized epidermis, permit some well-adapted species to survive several years without moisture in such regions as the Sonoran Desert of Baja California.

Agave. Exploration primarily for *Agave* collections was begun in September, 1950, by Gentry (Fig. 6) and was continued by him until July, 1952, except for a short period, June to September, 1951. During this exploration Gentry was assisted by E. C. Ogden (Fig. 7) from September to November, 1950, and by the late W. B. Fox (Fig. 8) from March to May, 1952.

In addition to the routine collections of 12- to 25-pound samples of leaves, and in some cases rootstocks and inflorescences, special repeat collections in lots of 500 to 2,000 pounds were occasionally needed for extraction of an ample quantity of the desired sapogenin. There developed so many requests at one time for species growing in Baja California that it was necessary to hire additional trucks to move the tonnage over 500 miles from places of origin to

FIG. 8. Fox in the field in 1952; Sierra de las Palmas, Baja California, Mexico.

FIG. 9. Miscellaneous plant materials from SPI field collectors, on arrival at the EURB laboratories in Philadelphia, before chemical analysis. (Photo: U.S.D.A.–M. C. Audsley).

the nearest railroad station in San Diego, California.

Another special field problem concerned the packing of a ton of spiny *Agave toumeyana* Trel. for shipment to the laboratory in Philadelphia (Figs. 9 and 10). This posed the possibility of considerable expense in time and money. Either the spines would have to be laboriously removed or a spine-proof container acceptable to the Railway Express agency had to be found. Fortunately, the botanist engaged in this procurement happened to be an experienced lettuce packer and he solved the problem neatly by packing the leaves in readily available lettuce crates with all spines turned inward.

The genus *Agave* was originally confined to North America, including Mexico and the West Indies, and Central America. Large numbers are now, however, cultivated as ornamentals (Fig. 11) and fiber plants throughout the warmer latitudes of the world. About 250 species have been collected by our Section for chemical analysis. Several of the species are among the world's major fiber producers: the henequens (*A. fourcroydes* Lem. and *A. zapupe* Trel.) of Mexico; and sisal (*A. sisalana* Perrine), mostly cultivated in the Old World. Two species are the primary sources of two major Mexican alcoholic drinks—*A. atrovirens* Karw., the pulque producer, and *A. tequilana* Weber, the source of tequila.

The greatest diversity of *Agave* is in the arid and semi-arid transition zone in the highlands of central Mexico,

where a large number of species and varieties occur, many of which are endemic and extremely local in distribution. The "Puebla Desert", covering parts of the States of Puebla (Fig. 12), Hidalgo and Oaxaca, is a typical region having a large number of endemic species. This region is also one of intensive cultivation of *Agave*. The greatest bulk concentration is in Baja California and the Coahuilan Desert, where massive populations of few species cover hundreds of square miles. All of the main areas of *Agave* distribution, except a large part of the Coahuilan Desert, have been explored rather thoroughly. The most intensive exploration has been in Baja California (Figs. 13 and 14) and Sonora in Mexico, and in the southwestern United States. The Yucatan peninsula remains unexplored; yet, because of its semi-arid climate and limestone nature, it should have in its flora a number of species of *Agave*.

The accompanying map (Map 1) shows the locations of *Agave* stands, not only in Mexico but also in other countries, where samples for chemical analysis were collected. These represent many species. The few unimportant West Indian collections are not shown. For uniformity in presenting the chemical findings, only collections of leaf samples are indicated. This excludes all gatherings of peduncles, inflorescences, fruits, and "heads" or meristems. Also

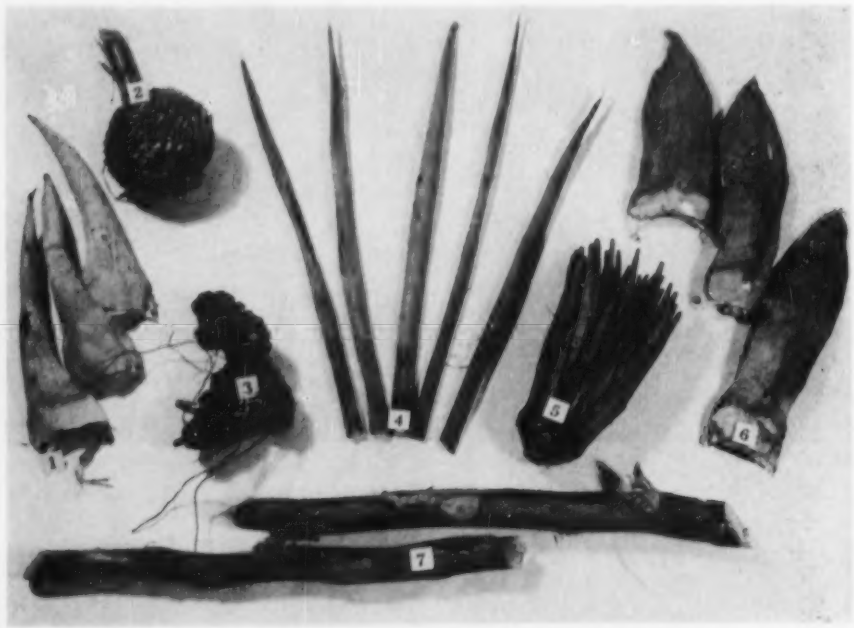


FIG. 10. Typical plant material sent by our field men to the EURB laboratories for chemical analysis: 1, leaves of *Agave cerulata* Trel.; 2, "head" of *Yucca peninsularis* McKelv.; 3, rhizome of *Dioscorea* sp.; 4, leaves of *Yucca schidigera* Roezl; 5, rosette of *Yucca peninsularis*; 6, leaves of *Agave nelsonii* Trel.; 7, sections of *Agave* sp. peduncle. (Photo: U.S.D.A.–M. C. Audsley).

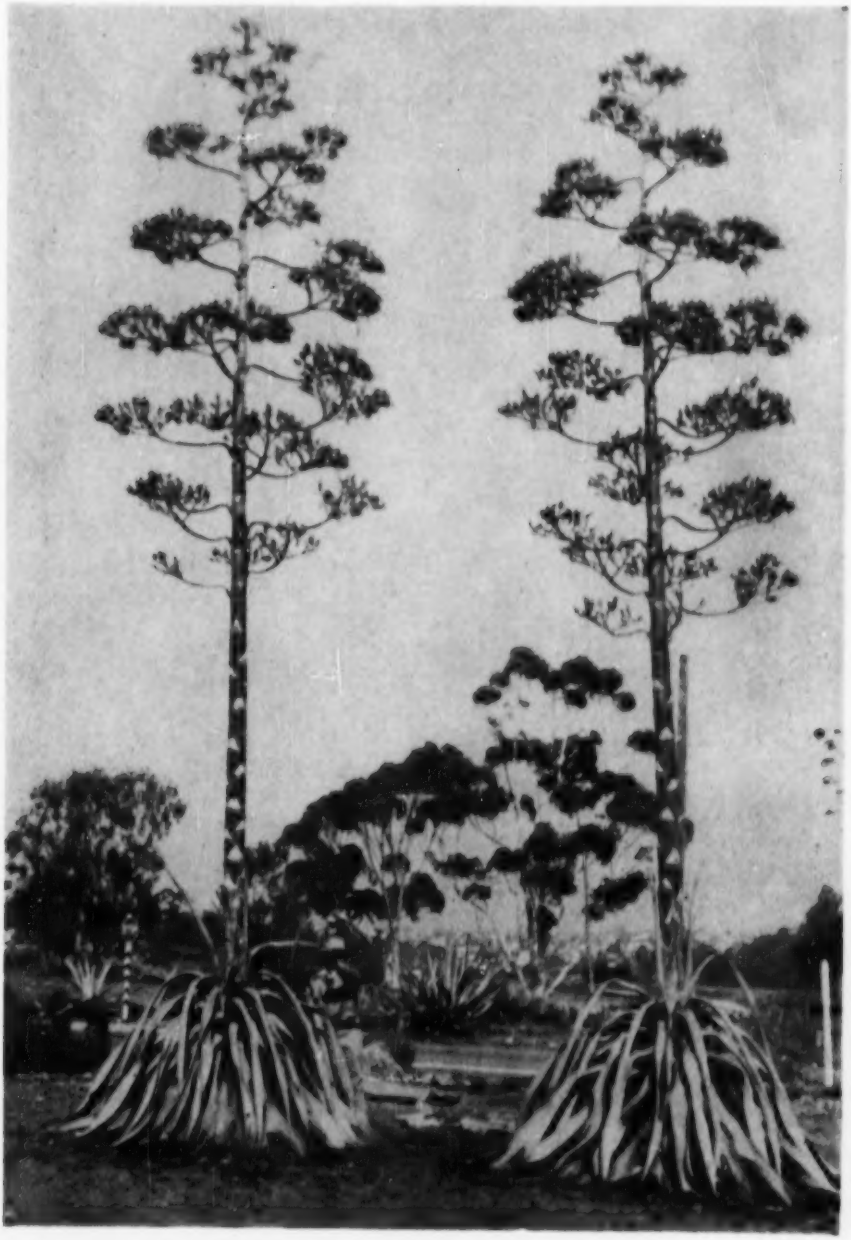


FIG. 11. *Agave promontori* Trel. in Balboa Park, San Diego, California.

MAP 1. *Agave*: localities in North and Central America where samples of leaves were obtained from many species and varieties for sapogenin analysis. • = 0.2% or more sapogenin; o = less than 0.2% sapogenin.

FIG. 12 (Upper). *Agave angustifolia* Haw. Ulibarri collecting a sample for chemical analysis near Puebla, Mexico, 1951. (Photo: E. C. Ogden).

FIG. 13 (Lower). *Yucca peninsularis* McKelv. Two forms, narrow-leaved at left, broad-leaved at right, growing together in Baja California, Mexico.

FIG. 14. *Agave goldmaniana* Trel. Flowering plant being examined by Argüelles in Baja California, Mexico; note *Idria columnaris* Kellogg in background, 1952.

omitted are the repeat samples obtained from the same localities and those obtained from institutional botanical gardens and experiment stations. Altogether, only about one-fourth of the total analysis samples collected are represented on the map. The occurrence of sapogenin, as shown by the map, is not limited to any particular region. More species yielding sapogenins as well as the highest yielders of sapogenins are, however, found in arid Baja California and in the semi-arid highlands of Oaxaca. In addition to seasonal variations of sapogenin content discovered in the same plant, it would appear that the sapogenin concentration in *Agave* is due perhaps more to genetic factors than to climatological. It is noteworthy, however, that sapogenins appear to be generally coincidental with climates having marked dry seasons. Supporting this observation is the scarcity of sapogenins among mesophytes and their absence from hydrophytes.

Dioscorea. Although Baldwin, after his return from Africa, spent two months, April 24 to June 24, 1950, in south-central Mexico making collections of *Dioscorea,* and Ogden with C. L. Gilly (Fig. 15) explored central Mexico together for the same purpose from January to May, 1950, Gentry has spearheaded the exploration for these plants.

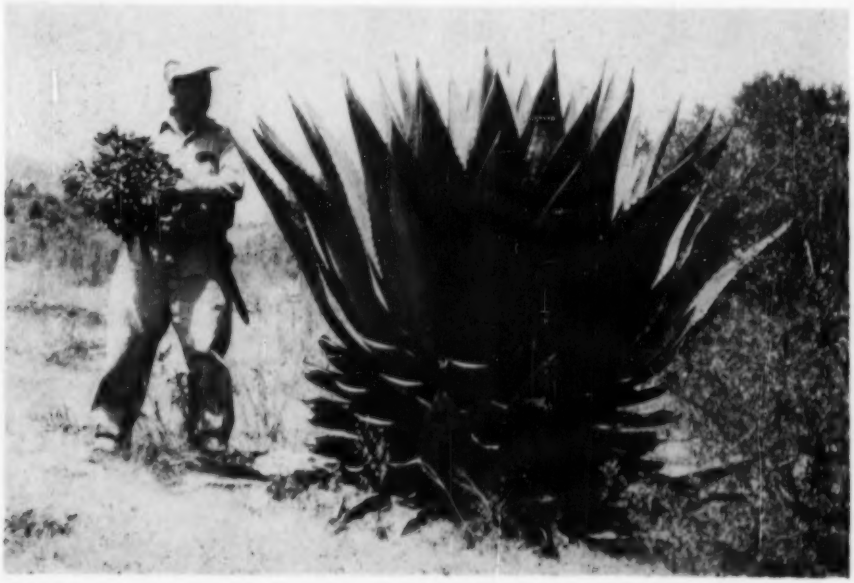


FIG. 15. Gilly in the field in Mexico, 1950, collecting samples of *Agave mezcal* Koch. (Photo: E. C. Ogden).

From June to September, 1951, he worked with Gilly in central Mexico, and from June to August, 1952, he was accompanied by Fox in the same region. From August, 1952, to March, 1953, he further explored not only central Mexico but also southern Mexico, including Chiapas, as well as Guatemala, Honduras and El Salvador for these extremely valuable plants.

In addition to the assemblages obtained by our own men, we have received

several high-yielding collections (especially from Veracruz) from cooperators, among them J. W. Ayers, president of Agrashell, Inc., and Temple Clayton.

An informal arrangement was made with Clayton to have living material sent to us, when possible, of all *Dioscorea* collections obtained for analysis by the Schering Corporation. These were to be held until analyses were made, so that they could be propagated and increased for agronomic tests if the analyses proved high. Collections were obtained by this cooperation not only from Mexico but also from Brazil and South Africa.

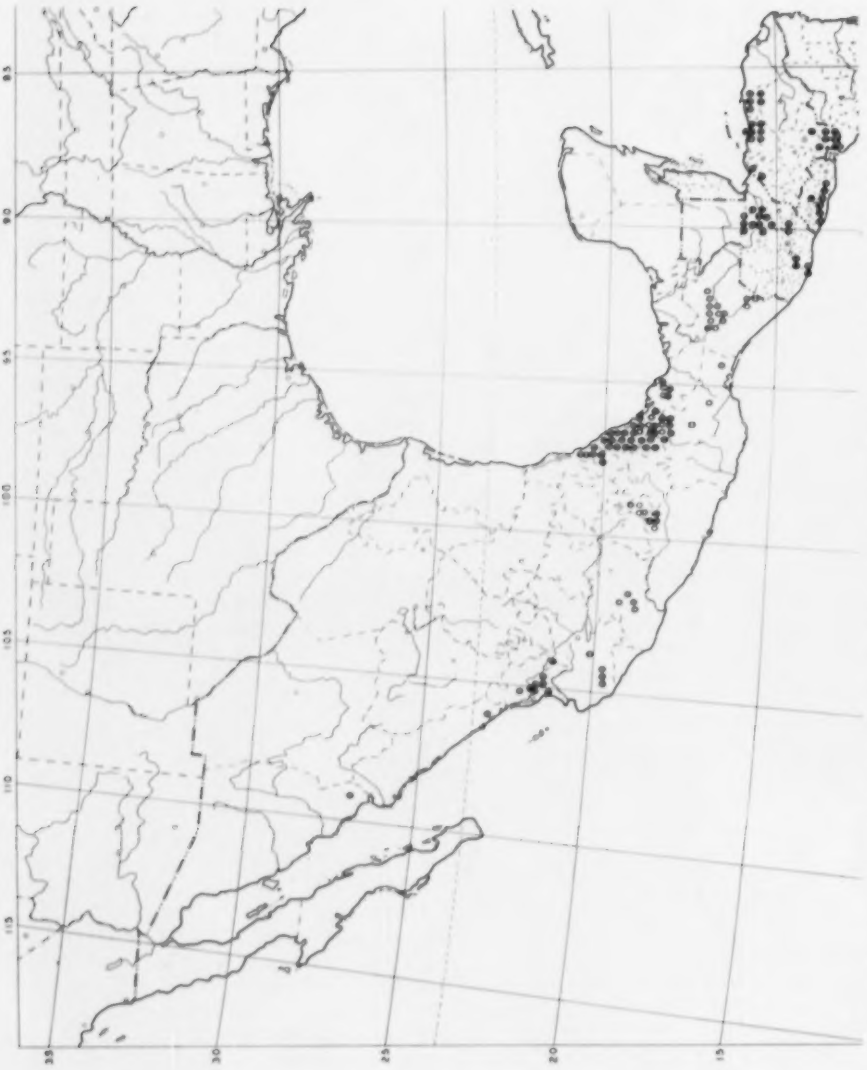
The various species of *Dioscorea* are commonly known as "yams". They are the true yams and are not to be confused with certain moist-fleshed varieties of sweet potato (*Ipomoea batatas* (L.) Lam.) to which the name is frequently applied. True yams and sweet potatoes are unrelated botanically, although the plants of these genera superficially resemble one another in that they are vines and produce underground tuberous roots or rootstocks. *Dioscorea*, however, is a representative of the Class Monocotyledoneae, *Ipomoea* of the Class Dicotyledoneae. The edible species of *Dioscorea* that have been cultivated from remote times produce starchy tubers similar to the white potato (*Solanum tuberosum* L.) in texture, food value and flavor. They form an important part of the food supply of the peoples of many humid tropical regions and are also used to a limited extent in warm temperate regions. They are widely grown in this hemisphere, and at one time a limited amount was produced in Florida to fill the demands of the West Indian population living in several of our large cities, especially New York.

The genus *Dioscorea* occurs rather abundantly in tropical and subtropical regions throughout the world, with several species in the temperate region. It consists of approximately 500 species, many of which are endemic in extremely restricted areas. A few species that are edible, being non-poisonous and lacking diosgenin, have been introduced into cultivation throughout the tropics. Aside from these very few used regularly as food, a few others serve as famine foods in emergencies after removal of their bitter principle by heat; and some species have been utilized occasionally as fish-poisons or insecticides by native populations.

Until the recent discovery of valuable chemical constituents in the underground parts of certain dioscoreas, the genus was of greater interest botanically than from any other point of view. There is great diversity in aspect, habit and underground parts of the species as well as in the flowers. The species are, in general, dioecious (Fig. 16). Only a few exceptions to this condition are known. The botanical classification has been based chiefly on the structure of the staminate flowers, specimens of which are absolutely essential for positive identification.

According to the most recent treatment, that of Matuda (46), 63 species of *Dioscorea* occur in Mexico. Of these, nearly one-tenth are a potential source of diosgenin, and of this number about half may be considered a practical source because of the high percentage yield. Several species are widely distributed in Mexico, and the genus seems to be lacking only in the truly desert areas of the country. Most of the species are apparently confined to the tropical and subtropical regions, where they are usually found on thinly or heavily forested slopes, in thickets, or infrequently in

FIG. 16. *Dioscorea elephantipes* (L'Hérit.) Engl. Staminate flowering plant from vicinity of Oudtshoorn, Cape Province, South Africa. (Photo: W. H. Hodge).



MAP. 2. *Dioscorea*: localities in Mexico and Central America where many collections of rootstocks of various species were obtained for chemical analysis.

open rocky places. The major area extends from the northeastern boundary of Puebla and Veracruz southward through the latter State and the adjacent parts of Oaxaca into the States of Tabasco and Chiapas. There is also an area in southern Sinaloa, Nayarit and adjacent Jalisco where similar species occur. As is true also of many other plant genera, southern Mexico seems to be a main center for development and distribution of *Dioscorea*, with representatives of many sections of the genus occurring in considerable numbers.

In addition to Matuda's work, which exclusively covers the species of *Dioscorea* native to Mexico, the only complete taxonomic study is that of Knuth, whose monograph of the whole family was published in 1924 (44). Schubert is at present preparing a treatment of the North and Central American species. Receipt of native material from this area, which might be incorporated in this study, will be appreciated.

Thus far, we have secured for chemical analysis 418 collections of *Dioscorea*, representing many species from various parts of the world, but mainly from Mexico and Central America (Map 2). Of these, 35 collections from Mexico and Central America have yielded, on a dry weight basis, 2% or more diosgenin. The largest number, 16, have yielded between 2% and 3% diosgenin. Half of these were collected in the State of Veracruz (Fig. 17); the remainder were from the States of Oaxaca, Nayarit, Jalisco and Chiapas, and from Guatemala. Eleven lots yielded between 3% and 4% diosgenin. Again, the largest number, six, were gathered in Veracruz, with three from Costa Rica and one each from the State of Oaxaca and from Guatemala. Three lots, one each from Oaxaca, Veracruz and Guatemala, yielded between 4%

FIG. 17. *Dioscorea* sp. A type with compressed discoid rhizomes from Veracruz, Mexico.

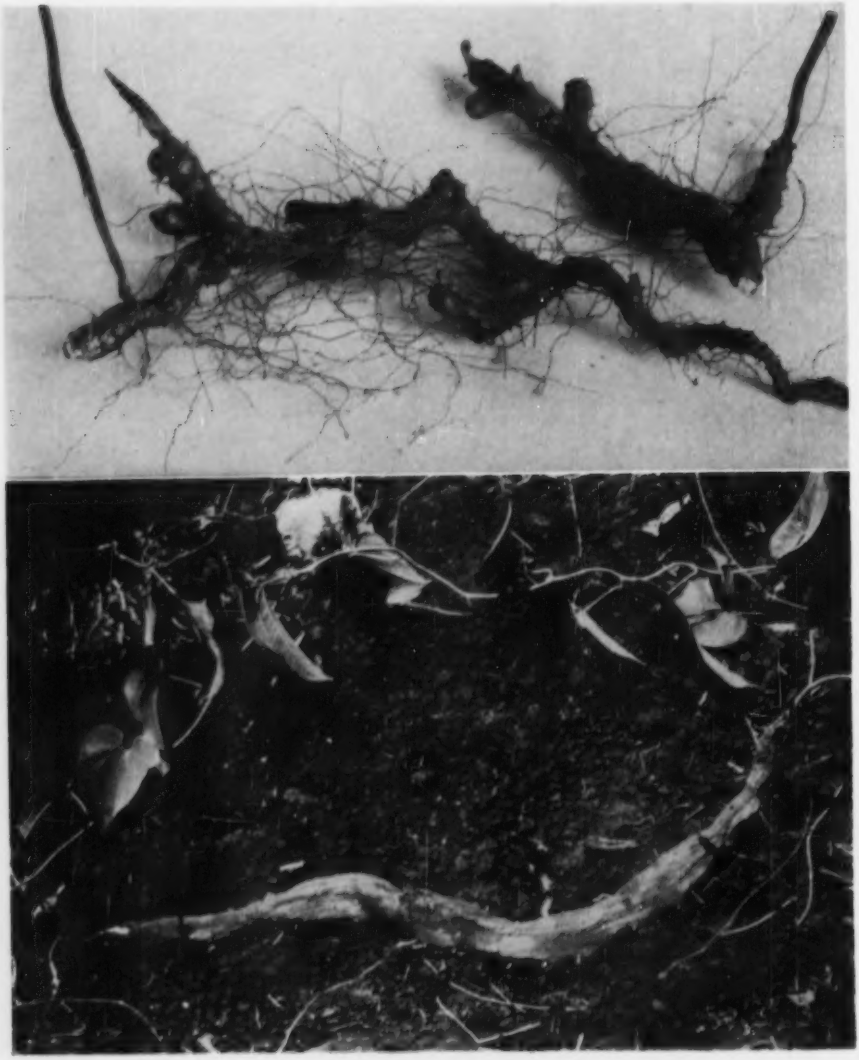


FIG. 18 (Upper). *Dioscorea quaternata* (Walt.) J. F. Gmel. Rhizomes collected in Maryland. About $\times \frac{1}{4}$.

FIG. 19 (Lower). *Dioscorea composita* Hemsl. Rhizome and portion of vine, Veracruz, Mexico. About $\times \frac{1}{12}$.

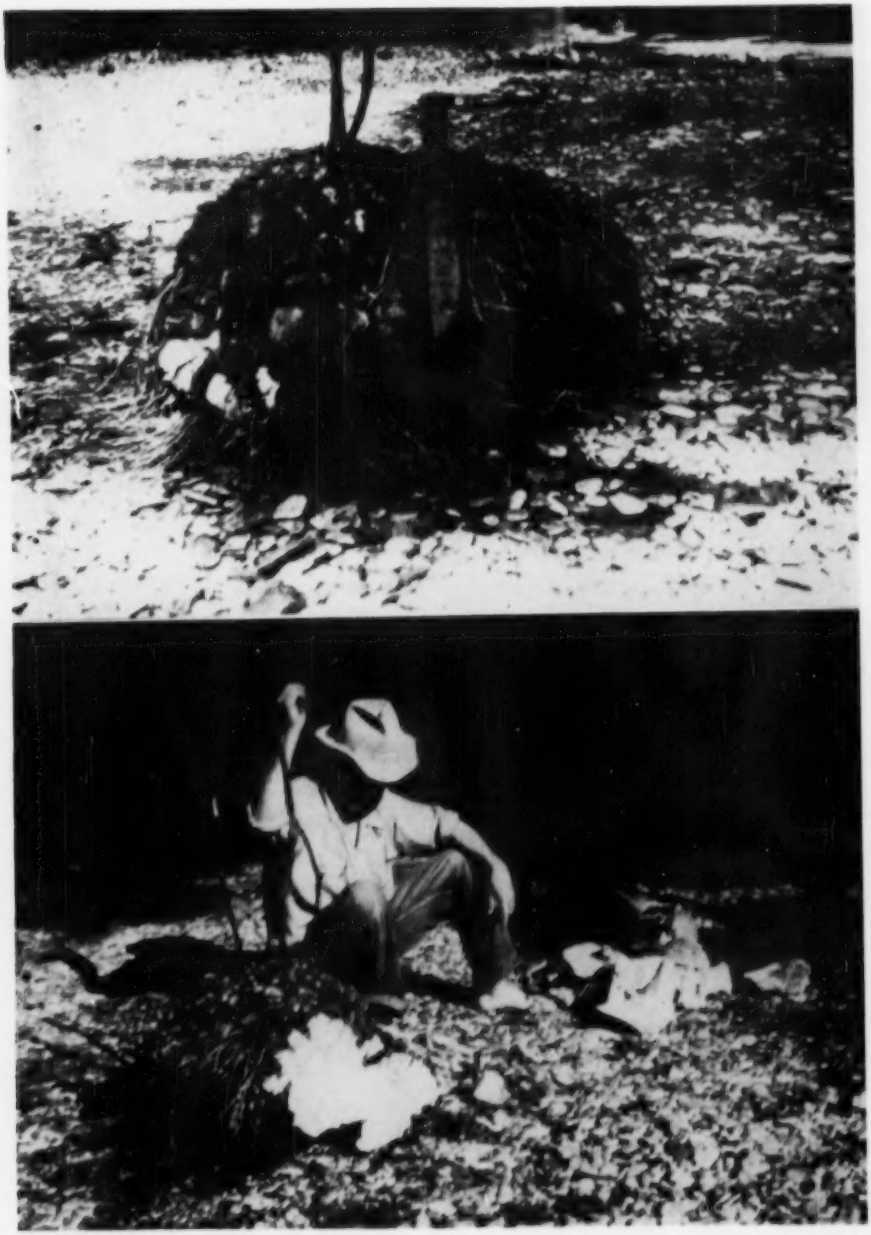


FIG. 20 (Upper). *Dioscorea mexicana* Guillem. Epigaeous "cabeza" type base with polygonal corky plates, Veracruz, Mexico.

FIG. 21 (Lower). *Dioscorea mexicana* Guillem. Preparing the above large specimen for drying and shipping, Veracruz, Mexico.

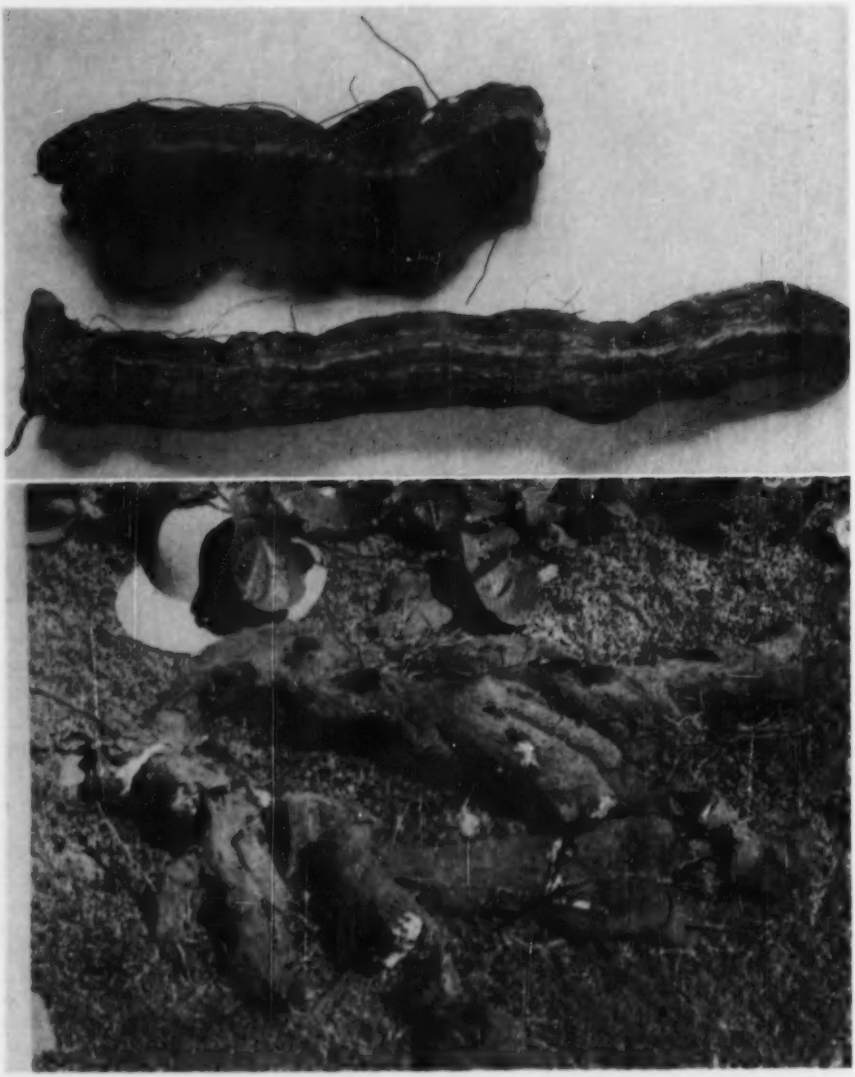


FIG. 22 (Upper). *Dioscorea floribunda* Mart. & Gal. (P.I. No. 200119). Rhizomes as they were received from Guatemala in March, 1952. About $\times \frac{1}{4}$.

FIG. 23 (Lower). *Dioscorea spiculiflora* Hemsl. A "pata de mula" type of rhizome, Michoacan, Mexico.

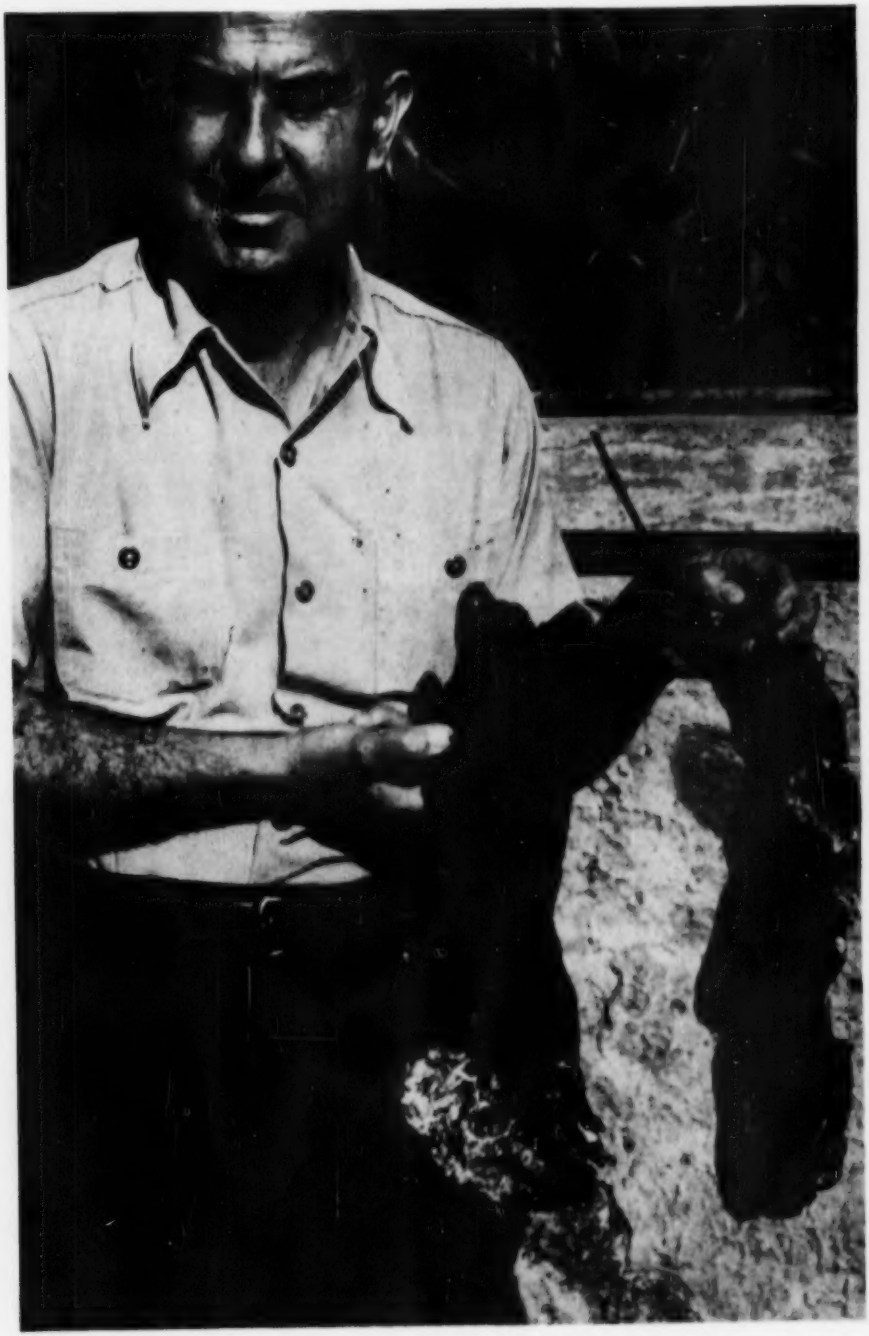


FIG. 23b. Correll holding two rhizomes of *Dioscorea spiculiflora* Hemsl. collected by him in Chiapas, Mexico, 1955. (Photo: G. F. Freytag).

and 5% diosgenin. The remaining five lots all came from Veracruz. Of these, two yielded between 5% and 6% diosgenin, one 6.9%, and two others 8.5% and 10.1%. The last two, as far as we know, are the highest analytic values known.

It is of interest to note that no appreciable amount of diosgenin has been found in the Old World species examined (39). Also, collections from the temperate zone have yielded very little diosgenin, although a species native to the eastern United States, *D. quaternata* (Walt.) J. F. Gmel. (Fig. 18), has been assayed with as high as 1.2% diosgenin.

At the beginning of the *Dioscorea* search, two species received the most publicity, *D. composita* Hemsl. (*D. tepinapensis* Uline) (Fig. 19) and *D. mexicana* Guillem. (*D. macrostachya* Benth.) (Figs. 20 and 21). The first species, known by the native name "barbasco", has rhizomatous underground parts which grow rapidly; the second, known as "cabeza de negro" from the large scaly epigaeous base which makes its greatest development above ground slowly and continuously over a long period of years, often being attacked by termites within while continuing its external growth.

In our investigations the barbasco type has been of greatest interest, and among the more productive species, *D. composita* stands high. *Dioscorea floribunda* Mart. & Gal., known from southern Mexico and Central America (Fig. 22), and *D. spiculiflora* Hemsl. (Figs. 23 and 23b), from southern Mexico, are also extremely interesting.

Because of an inclination toward the spectacular where only a glimpse of success may be first evidenced, a note of caution and restraint is in order here. In some popular reports published in newspapers and news magazines are to be found such erroneous statements as "The Yucca, or common century plant, . . . is one of the best cortisone producers", or "He seeks a variety with the highest possible cortisone content, and to date has harvested yams yielding as much as 5 per cent cortisone". Many such startling published statements that have permeated the press during the last few years could be cited.

The truth, as far as we know, is that, although cortisone is now being produced commercially from both diosgenin and hecogenin, the main source is still bile acids. Notwithstanding, the cortisone precursors from plant sources are potentially of great importance in the future production of this drug and related compounds. At present, diosgenin is one of the best sources for the manufacture of sex hormones.

Central America

Although some field work in this program has been accomplished in Central America, the region as a whole must be considered as largely unexplored. It, as well as certain parts of Mexico, remains a region of tremendous possibilities. Altogether, only a few hundred samples of miscellaneous plants have been obtained for chemical analysis from this rich region.

From March to June, 1951, O. W. Norvell collected in Guatemala, Honduras, El Salvador and Nicaragua, and, as noted previously, in early 1953 Gentry explored in Guatemala, Honduras and El Salvador. Norvell, who was primarily in the field to collect wild and cultivated strains of bean (*Phaseolus*), made incidental collections of miscellaneous plant samples, including *Dioscorea* and *Agave*, while Gentry concentrated on *Dioscorea* with significant success.

Besides these staff men, several individuals have made valuable contributions to our work in Central America; L. O. Williams of the Escuela Agricola Panamericana in Tegucigalpa, Honduras; J. R. Hunter of Servicio Tecnico Inter-Americano de Cooperacion Agri-

FIG. 24 (Upper). Earl E. Smith in the field in the Chilean Andes, 1954.
FIG. 25 (Lower). Correll, right, and assistant in the field in Cuba, 1953; note sacks of plant samples.

FIG. 26 (Upper). *Yucca elephantipes* Regel. Large plants growing near Christiansted, Saint Croix, American Virgin Islands.

FIG. 27 (Lower). Julian Acuña, center, and Roig y Mesa, right, with driver in the field in Cuba, 1953.

FIG. 28. Large portions of rhizomes of *Dioscorea floribunda* Mart. & Gal. being benched in a peat moss medium by Gerald Seaton at our Plant Introduction Garden, Glenn Dale, Md.

cola (STICA), San José, Costa Rica; and A. M. Bouché in the Panama Canal Zone.

South America

If Central America is to be considered scarcely explored, South America, relatively, must be classed as essentially virgin territory. Only two limited areas in this vast region have been explored for plants, especially *Dioscorea*, that have been examined in this project. These are parts of Chile, Peru and Bolivia, and a portion of the State of Minas Geraes, Brazil.

In the fall of 1951 we received from Clayton about 40 collections of *Dioscorea* from Brazil. From October to June, 1954, Earl E. Smith (Fig. 24), now with International Cooperation Administration (ICA), was sent to Chile, Peru and Bolivia specifically to obtain *Dioscorea* samples. A special effort was to be made to get material from the temperate zone of southern Chile in the hope that a high-yielding species from this region would be more amenable to cultivation in our southern States. Unfortunately, not only were the yields from the species of this region low, but the rhizomes and tubers were small and impracticable for cultivation. The Chilean area is the center of development of a group of sections in the genus *Dioscorea* whose species are notable for their low stature and small underground parts. Although these are highly technical and botanically interesting species, they prove to be impractical. Smith's very good herbarium specimens will help to solve many taxonomic problems.

Smith received excellent cooperation not only from various government agencies but also from many individuals during his field work. The following were especially helpful: Carlos Muñoz, of the Chilean Department of Agriculture; Benkt Sparre, of the University of Concepcion, who made several trips with Smith and has since cooperated with SPI; Ramón Ferreyra, of the Museo de Historia Natural "Javier Prado", Lima, Peru, who traveled along to several good collecting areas and who has since been helpful in arranging for repeat collections; Martín Cardenas, of the Universidad Autonoma "Simon Bolivar", Cochabamba, Bolivia, who also pointed out good collecting areas and has since continued cooperation.

West Indies

Two of the authors, Correll and Schubert, have made explorations in the West Indies. Correll (Fig. 25), from the first of April to the middle of June, 1953, explored Cuba, Puerto Rico and the American Virgin Islands for breeding material of sweet potato (*Ipomoea batatas*) and cotton (*Gossypium* spp.), accompanied by Julian C. Miller, of Louisiana State University. Incidental to this work, a number of samples (Fig. 26) were obtained for chemical analysis in both the cortisone and heart drug programs. Schubert, early in 1954, did further exploration work in Cuba, chiefly for the "heart" project, but she did some collecting for this program too. In Cuba unlimited and enthusiastic assistance was received from Julian Acuña, Botanist, and Juan Tomas Roig y Mesa, Pharmacologist, of the Estacion Experimental Agronomica, Santiago de las Vegas (Fig. 27), and from I. D. Clement, Director of the Atkins Garden and Research Laboratory of Harvard University at Central Soledad, Cienfuegos. In the fall of 1954, with the official cooperation of the U. S. Federal Experiment Station at Mayaguez, Puerto Rico, Schubert explored on that island, but only for "alkaloid plants".

United States

Approximately one-third of the general collections have been made in the United States. For the most part, these

FIG. 29. *Dioscorea floribunda* Mart. & Gal. Seedlings growing on screened sphagnum moss at our Plant Introduction Garden, Glenn Dale, Md.

FIG. 30. *Dioscorea floribunda* Mart. & Gal. Plants growing at our Plant Introduction Garden, Glenn Dale, Md.

FIG. 31. *Dioscorea floribunda* Mart. & Gal. Leaf-cuttings rooted in coarse sand at our Plant Introduction Garden, Glenn Dale, Md.; note variegated leaves of this selection.

samples were brought together by botanists and others working on a cooperative basis. Those who have collected the most material and their regions of exploration are: W. H. Duncan, from Georgia and Florida; R. K. Godfrey, especially from North Carolina and Florida; B. H. Warnock, from the Trans-Pecos region in west Texas; R. R. Cruse, from the desert region of Arizona; C. F. Reed, from eastern and central United States.

Although most of the collections from the United States represent a general sampling of the plant kingdom, emphasis was placed, especially in the beginning, upon various groups, among which were *Veratrum* and *Yucca*. Nearly all of the North American species of *Veratrum* were obtained for analysis and propagation. All of the species of *Yucca* known to occur in eastern United States were secured, as well as most of those growing in the western states.

Miscellaneous Regions

Although individual samples have been received from many scattered regions, too numerous to cite, it is of interest to note several of the more prominent to illustrate the diversity of the area covered. Among these are the collections obtained by Gentry in India, Pakistan and Afghanistan; by E. H. Walker, of the National Herbarium, Smithsonian Institution, in Okinawa; by H. Hurlimann (through H. G. MacMillan, of the South Pacific Commission) from New Caledonia; and by Godfrey in Turkey.

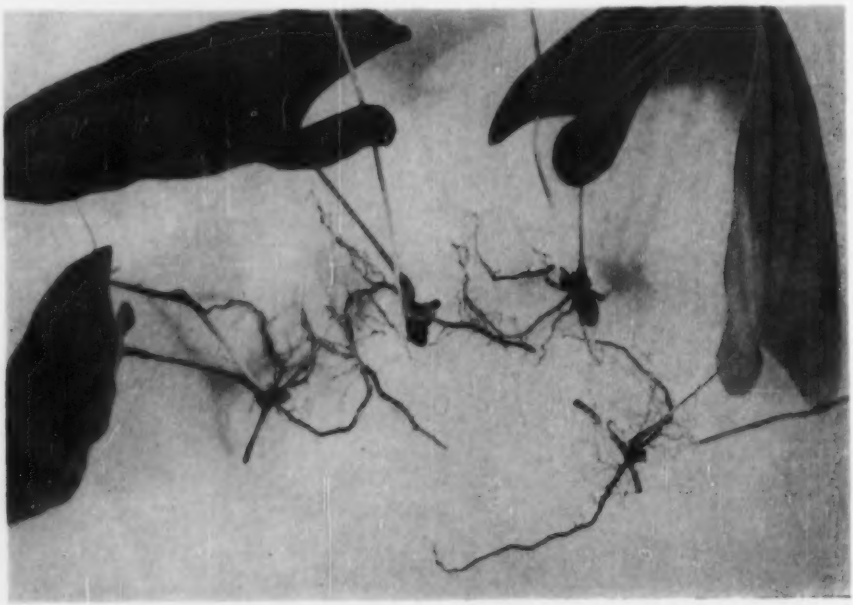


FIG. 32. *Dioscorea floribunda* Mart. & Gal. Mallet cuttings after initial rooting and beginning of tuber-formation at our Plant Introduction Garden, Glenn Dale, Md.

HORTICULTURE

Propagation studies in *Strophanthus* were made at Glenn Dale by Creech and

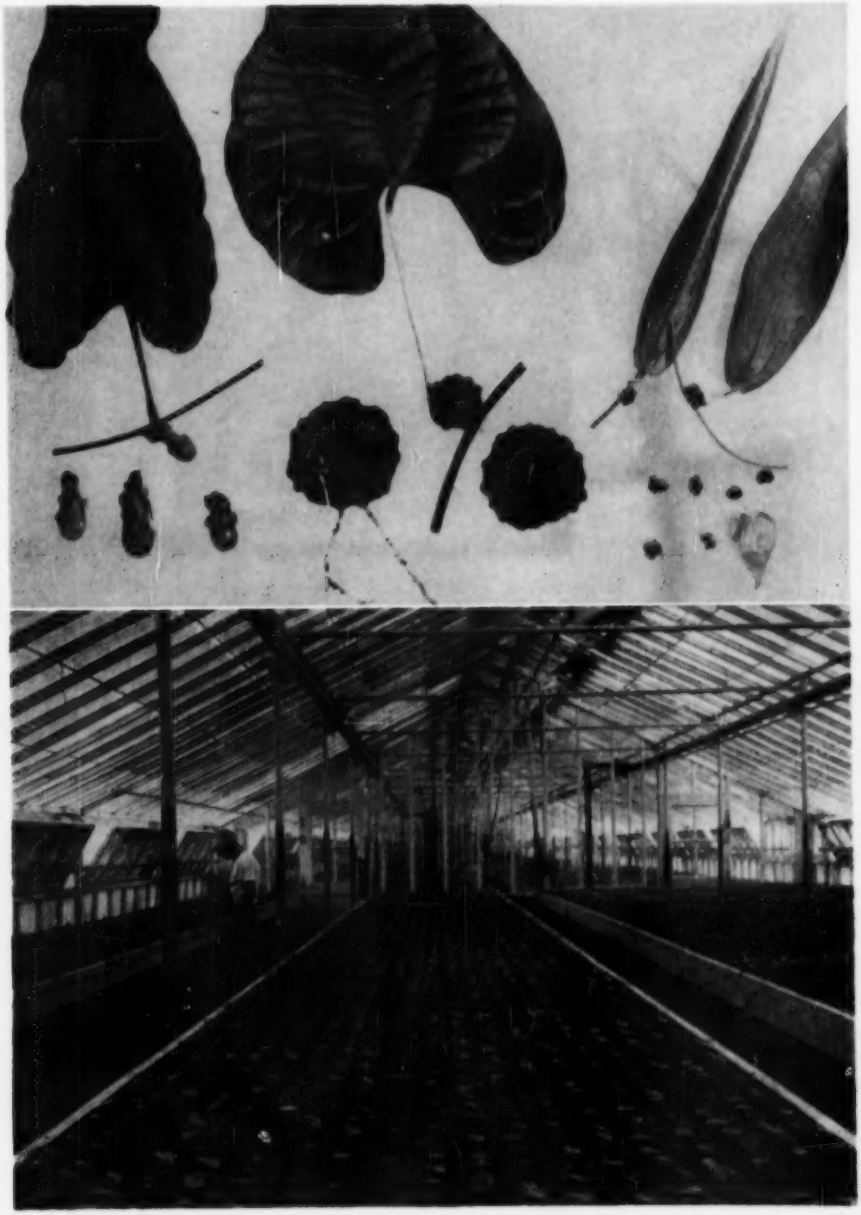


FIG. 33 (Upper). Aerial tubers of three species of *Dioscorea*, a common occurrence in this genus.

FIG. 34 (Lower). Seedling plants of *Dioscorea floribunda* Mart. & Gal. after 20 days from benching in a leaf-mold medium; compacted soil surface is being broken to provide aeration; at our Plant Introduction Garden, Glenn Dale, Md.

Dowdle, the results of which were published in 1952 (1). Similar but more elaborate studies have been made by Hawley at the same Station on the propagation of *Dioscorea*, the results of which are incorporated in the present paper.

The primary objective of the work with *Dioscorea* at Glenn Dale is to maintain propagation stock pending the outcome of the chemical analysis of each accession. Propagation and cultural methods and requirements are determined, and flowering specimens are collected to facilitate the taxonomic work on the genus. Some species are endowed with handsomely variegated leaves, and several of these have been selected for evaluation as possible ornamentals.

More than 500 collections of *Dioscorea* have been received at Glenn Dale in the course of this program. At present there are under greenhouse culture 348 accessions, comprising many species and varieties. A few tubers of each accession are being maintained during this evaluation period until all objectives are met.

Treatment of Materials Received

Most of the dioscoreas are received as tubers (Fig. 22); sometimes, unfortunately, in a state of decomposition. To arrest such a condition, rotted parts are removed and the tubers are benched in peat moss (Fig. 28) that has been slightly moistened to encourage new growth.

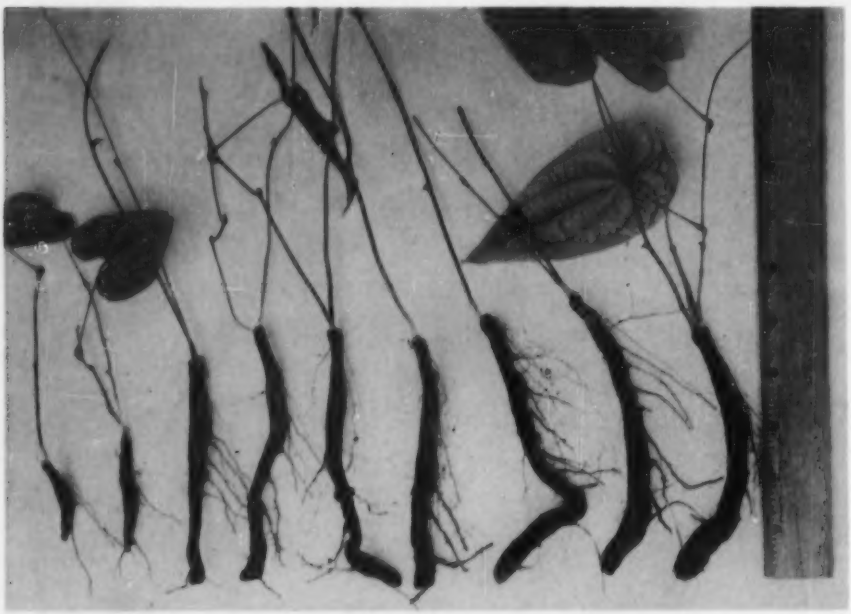


FIG. 35. *Dioscorea floribunda* Mart. & Gal. Seedlings after 13 months growth at our Plant Introduction Garden, Glenn Dale, Md.

In compliance with quarantine regulations, tuberous material is first grown in isolation greenhouses partitioned off into separate sections. All openings such as doors, windows and ventilators are covered with 30-mesh screening, and peri-

FIG. 36 (Upper). *Dioscorea floribunda* Mart. & Gal. Tubers being dug for shipment to the field, at our Plant Introduction Garden, Glenn Dale, Md.

FIG. 37 (Lower). *Dioscorea* species being grown for collection of herbarium specimens at our Plant Introduction Garden, Glenn Dale, Md.; flowering usually occurs in late summer and fall.

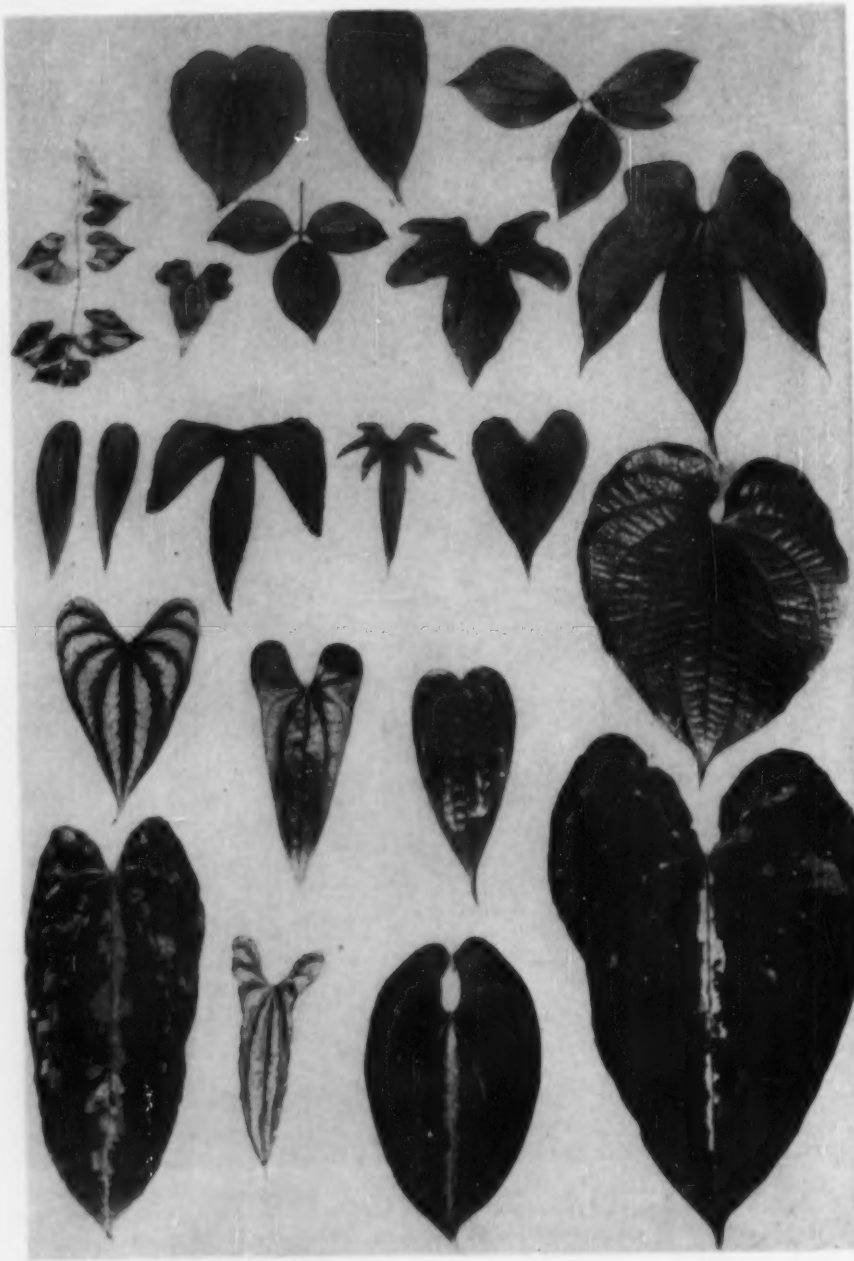


FIG. 38. *Dioscorea* species. Leaves showing variations in shape, size and color; some with good ornamental possibilties.

FIG. 39 (Upper). Clonal collection of *Yucca gloriosa* L. under cultivation at our Plant Introduction Garden, Savannah, Ga.; note the *Dioscorea* plantings on bamboo supports in background, 1954.

FIG. 40 (Lower). *Strophanthus intermedius* Pax (P.I. No. 189622) in fruit at U. S. Federal Experiment Station, Mayaguez, P. R., in 1954, from two-year-old seedlings originally planted in 1951.

odic fumigations with insecticidal aerosols are applied to prevent introduction of foreign insects. Frequent examinations are made by Quarantine Service Inspectors who decide whether and when the plants are disease-free and can be released from these restricted quarters.

About one-fourth of the accessions have been introduced as seed. *Dioscorea* seed germinates in three to eight weeks when sown on flats of shredded sphagnum moss (Fig. 29). The seed has a moderately long life, especially when stored dry at 33° F. Under such storage conditions no reduction in viability has been noted after 18 months. If mature when harvested, the seed will yield 60% to 80% germination. Transplanting from the moss is not difficult, and very few plants are lost in the transfer.

Propagation

When dioscoreas have grown sufficiently to produce a quantity of propagating material (Fig. 30), cuttings are selected on the basis of maturity of the vines. New wood that will not wilt in the cutting bench is removed from the plants and divided into single-node cuttings consisting of a leaf with its axillary bud and a short section of the stem. The cuttings can be made with a knife or sharp pruning shears. Cuttings are inserted in well-washed coarse sand (Fig. 31) by placing them in a narrow trench one inch deep. A light packing with the finger tips is followed by a syringing of the bench with water to settle the sand around the base of the cuttings. Shade applied to the roof of the propagating house reduces the light intensity at the bench surface to about 200 foot-candles. The rooting medium temperature is kept at 68° to 72° F., and a minimum night temperature of 60° is maintained within the house. Under these conditions rooted cuttings can be produced in 14 to 21 days. While the cuttings are rooting they form very small tubers, one-eighth to one-fourth inch in diameter, at the leaf axil (Fig. 32). At this stage the young plants are removed from the propagating house and transplanted to the greenhouse bench.

Aerial tubers occur profusely on some species (Fig. 33) and provide a good means of propagation if planted soon after ripening. They will not tolerate shipping and after several days in transit cannot be grown successfully.

Greenhouse Culture

Except for the peat moss growing-medium, utilized for starting newly received tubers, the standard growing-medium at Glenn Dale consists of a mixture of leaf mold, peat moss and sand, the proportions being 2–2–1, respectively. To assist in controlling soil-borne pests, the leaf mold is fumigated with methyl bromide before it is incorporated into the mixture.

When young plants are benched they are planted on three-and-one-half-inch centers (Fig. 34). At this spacing they can be grown for at least one year without crowding the tubers. Occasional applications of liquid fertilizer to the medium surface are beneficial to the plants.

Greenhouse temperature is maintained at a minimum of 60° F. at night, and humidity at 40% to 50%. Since most species of *Dioscorea* are found in at least partial shade in nature, daylight intensity is reduced to approximately 600 foot-candles by a heavy application of lime shade to the outside of the house.

The vines are supported by twine and wires strung over the benches (Fig. 30). This practice is necessary to provide ventilation through the mass of foliage and thereby prevent decomposition of the lower leaves that would otherwise be smothered. *Dioscorea floribunda* Mart. & Gal. will produce finger-size tubers in

FIG. 41. *Strophanthus sarmentosus* DC. H. F. Loomis examining plants growing at our Plant Introduction Garden, Coconut Grove, Fla., 1953.

FIG. 42 (Upper). *Strophanthus preussii* Engl. & Pax. Fruiting plants in the trial garden of Firestone Plantations Company, Harbel, Liberia, 1955.

FIG. 43 (Lower). *Strophanthus preussii* Engl. & Pax. Fruits and leafy branches collected in Gold Coast by Baldwin, 1949.

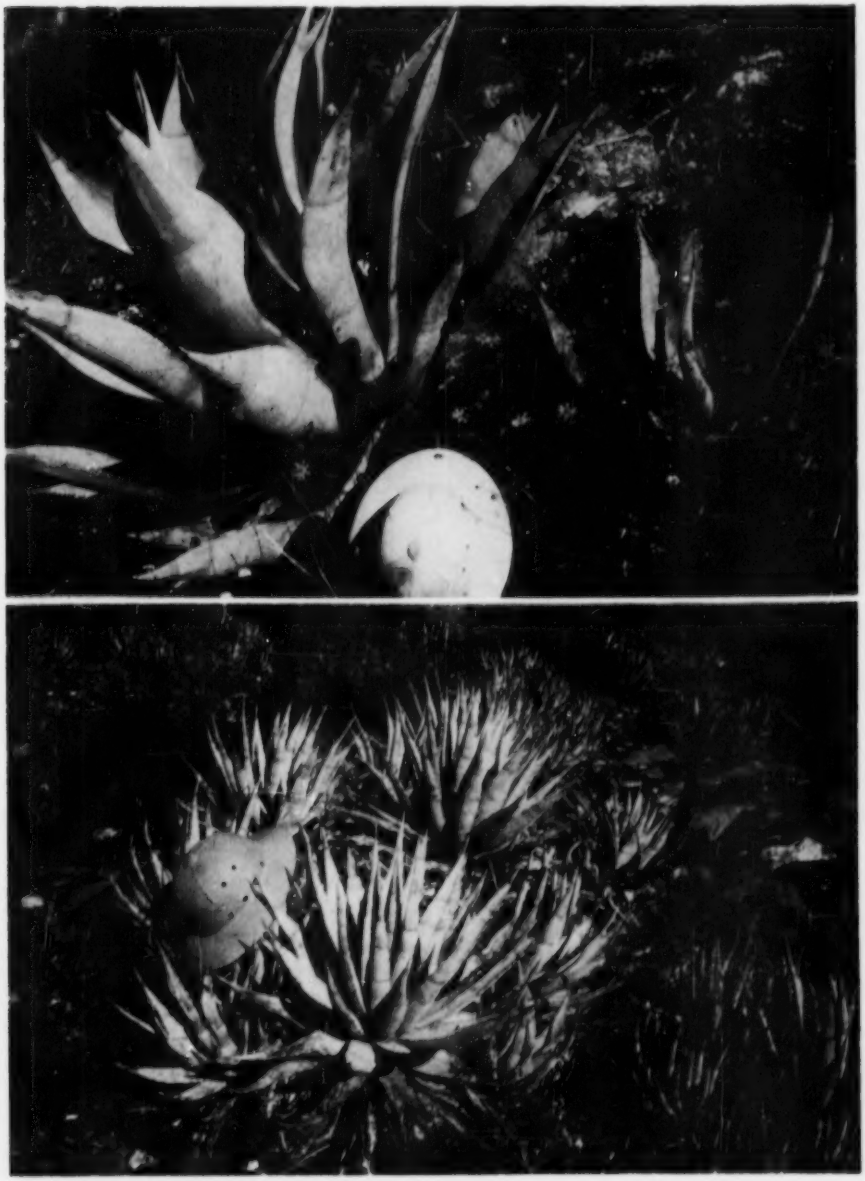


FIG. 44 (Upper). *Agave promontori* Trel. Broad-leaved form on Sierra Laguna in Baja California, Mexico.

FIG. 45 (Lower). *Agave cerulata* Trel. An abundant plant in Baja California, Mexico.

five to eight months under these cultural conditions.

Tuber Storage

The short days and cooler weather of autumn are conducive to dormancy for many species. This situation is sometimes utilized to clean and re-inventory benches containing plants that have been under cultivation more than a year. To place the tubers in complete dormancy, watering is reduced day by day until the soil is completely dry. At this point tubers can be removed and stored for a few months in a cool location supplied with moderate ventilation and 20% to 30% humidity. It is advisable to have the material thoroughly surface-dried before it is placed in storage. While most species will store well in burlap sacks, there are a few that will not withstand bagging of any kind. Such tubers must be laid out or stored in a manner that will permit free air circulation. If the location is too dry, some species will not survive more than two or three months.

Harvesting and Shipping

Tubers of *Dioscorea floribunda* will attain shipping size in nine to 15 months (Fig. 35). Removal from the greenhouse bench is preceded by a drying-off period which slows growth and hardens the tubers so that they will withstand the shock of handling and shipping. Vines are cut back to the base and the tubers are lifted and shaken free of soil (Fig. 36). Any vegetation left on the tubers will die back completely, and new shoots will develop when the tubers are replanted. Packing containers are of a slat type, such as celery crates, to allow for ample ventilation. Packing material consists of slightly moist sphagnum moss. Tubers packed in this manner will stand at least several days in transit with no detrimental effects.

Herbarium Specimens

Narrow benches along the sides of the greenhouses are used for plants grown as a source of herbarium specimens (Fig. 37). One row running the length of these benches contain all accessions from which specimens are needed. As the vines grow they are restricted to single stems directed over the benches and across the greenhouse. By training the plants in this manner, many species can be grown in proximity without excessive entanglement.

Selection of Possible Ornamental Species

There is wide variation in the size, shape, color and texture of the leaves (Fig. 38). Many are attractive enough to be suitable for window planting in cold areas or for patios where the climate is warm enough for outdoor culture. Some of the edible dioscoreas have been used ornamentally in warm regions to screen unsightly objects or to give privacy. Because of its luxuriant top growth, *Dioscorea* is ideal for this purpose. Some of the collections assembled at Glenn Dale could doubtless be used just as well, with the added feature of a more decorative foliage. It is quite possible that some of these plants could be grown indoors as is *Philodendron*. Studies along these lines are now being conducted at Glenn Dale.

FIELD TESTING AND EVALUATION

The decision to proceed with agronomic studies on any given introduction of *Strophanthus* or *Dioscorea* depended upon the results of chemical analysis. If the results were sufficiently high, preliminary cultural investigation was initiated. In the case of *Agave*, no agronomic studies other than maintenance of a living collection in southern California has been undertaken. As noted before, we have at present under cultivation

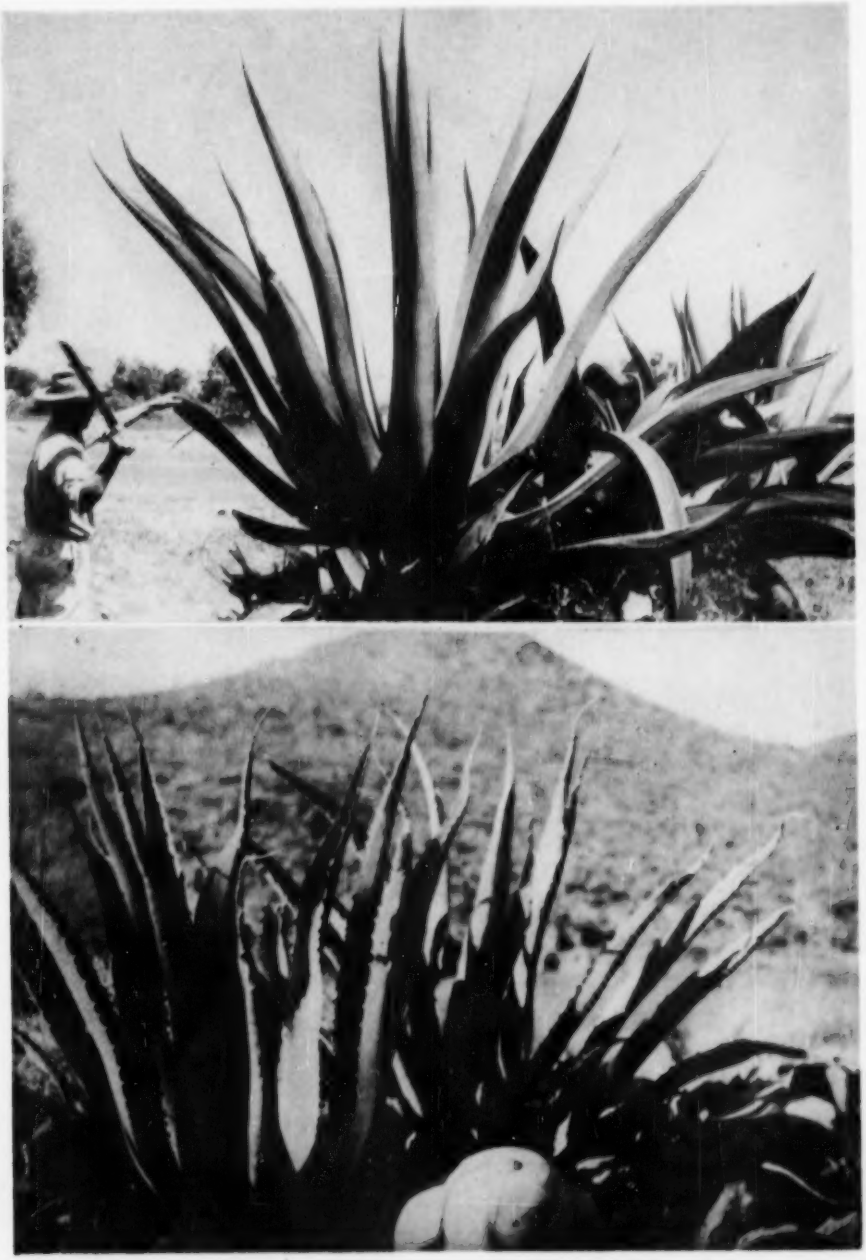


FIG. 46 (Upper). *Agave mapisaga* Trel. Argüelles cutting a leaf sample for chemical analysis in Puebla, Mexico, 1952.

FIG. 47 (Lower). *Agave aurea* Bdge. An abundant plant in Baja California, Mexico.

FIG. 48. David Bisset examining plants of *Dioscorea floribunda* Mart. & Gal. growing on bamboo supports at our Plant Introduction Garden, Savannah, Ga., 1953.

species of all three genera that have given the highest yield of cortisone precursors yet found. In the early stages of this program, plants of *Yucca gloriosa* and *Y. filamentosa* L. from throughout their area of distribution were assembled at our Savannah, Georgia, Plant Introduction Garden, where they are thriving (Fig. 39).

Strophanthus

Plants of more than 50 introductions of *Strophanthus*, representing more than 30 species, are being maintained at the Federal Experiment Station in Mayaguez, Puerto Rico, as a natural planting on a forested slope. This collection, which includes some introductions whose seeds contain as much as 1.2% sarmentogenin, is a germ plasm repository in case interest in the species of this genus as a source for cortisone is revived by new discoveries in the study of their chemistry which is still in progress. Besides maintaining this general collection, Mayaguez is conducting various cultural experiments on several strains of *S. intermedius* Pax. and *S. sarmentosus*. These experiments, under the supervision of H. F. Winters, include study of such factors as mulching, fertilizing, trellising and various supports, pruning, grafting and pollination, to determine their effect upon flowering and fruiting. The plants were originally set out in 1951. From these plants, started from seeds sown in 1950, an average of nearly two fruits per plant for all experiments was produced in 1954 under open-pollination (Fig. 40). The trellised plants, alone, produced almost four fruits per plant, and one plant yielded a total of 39 fruits. The variability in fruit production would appear to be genetic and not due to age of plant. Therefore productive strains might be obtained by selection.

Besides the plantings at Mayaguez, a small collection of specimen plants is being held at the Section's Coconut Grove Plant Introduction Garden (Fig. 41), and a collection has been placed at the Firestone Plantations in Harbel, Liberia (Figs. 42 and 43). Also, plants of 13 species were distributed in 1951 to several locations in the western hemisphere to obtain as much information as possible regarding their tolerance and behavior under widely varying conditions. These areas included Mexico, Guatemala, Nicaragua, Cuba and southern California.

FIG. 49. *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783). Rhizomes after one year's growth in the field at our Plant Introduction Garden, Savannah, Ga., 1953. About × ¼.

Although at present there is a diminished if not complete lack of interest in *Strophanthus* as a practical source of cortisone, the agricultural experiments started in Mayaguez in 1951 are being carried to completion. This genus, already a drug source of some prominence, has never been studied culturally. The

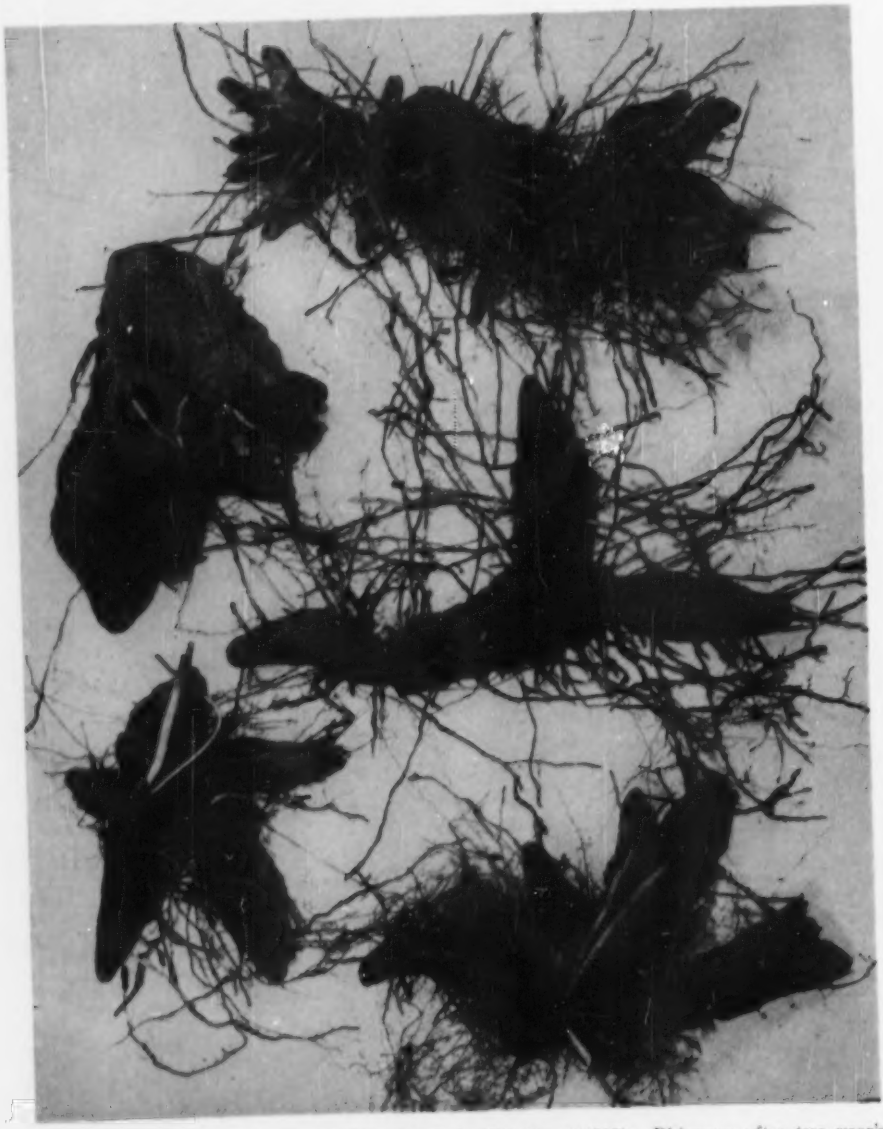


FIG. 50. *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783). Rhizomes after two year's growth in the field at our Plant Introduction Garden, Savannah, Ga., 1954; originally from Veracruz, Mexico. About × ¼.

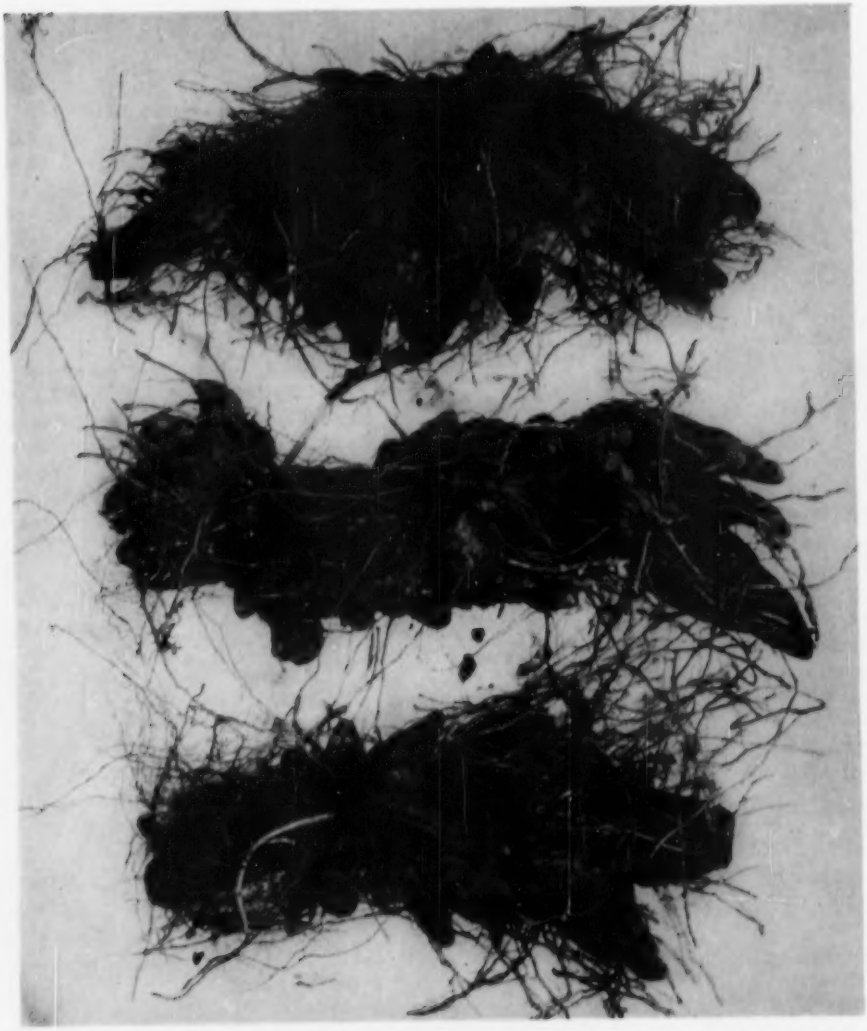


FIG. 51. *Dioscorea floribunda* Mart. & Gal. (P.I. No. 200119). Rhizomes after two year's growth in the field at our Plant Introduction Garden, Savannah, Ga., 1954; originally from Guatemala. About × ¼.

experiments now nearing completion should provide much valuable and useful information concerning its cultural needs.

Agave

In the course of this work about 600 collections of *Agave* have been obtained for chemical analysis. It is estimated that these include about three-fourths of the species found in nature. A number of them have a rather high sapogenin content, usually confined to the leaves. Among these are *A. promontori* Trel. (Figs. 11 and 44), *A. vilmoriniana* Weber, *A. roseana* Trel., *A. nelsonii* Trel., *A. cerulata* Trel. (Fig. 45), *A. sobria* Brdge., *A. sullivanii* Trel., *A. toumeyana, A. atrovirens, A. mirabilis* Trel., *A. mapisaga* Trel. (Fig. 46) and *A. aurea* Brdge. (Fig. 47). One of these, *A. roseana,* has yielded 2.5% hecogenin, the highest yet found in *Agave*.

We have not undertaken any cultural studies of this genus except the small experimental plot of *A. toumeyana* at the U.S.D.A. Field Station in Sacaton, Arizona, in 1951. This experiment was discontinued in 1953 before any worthwhile results could be obtained. The short period of planting, however, gave little encouragement to the possibility of growing this species as a crop plant.

In anticipation of possible future cultural studies on *Agave*, as noted before, a living collection paralleling the chemical analysis samples was assembled at the Huntington Botanical Gardens in San Marino, California.

In our opinion, the fiber interests and research agencies in the United States may be overlooking an excellent opportunity to establish a new fiber industry in our own Southwest. There is no good reason why we should, through the ages, complacently continue to accept only three of the numerous *Agave* species as basic sources of fiber, an extremely strategic item to our defense and welfare. The selection of these three species, the henequens (*A. fourcroydes, A. zapupe*) and sisal (*A. sisalana*), for cultivation was not originally done on a scientific basis. They had long ago, doubtless through fortuitous circumstances, become the traditionally grown fiber plants of Mexico and the Old World, respectively. Our recent investigations have uncovered good fiber species, also high in hecogenin content, that would be hardy for certain areas in our southwestern States. The ideal combination, producing under cultivation a species of *Agave* with superior fiber in which a high hecogenin content would reside in the bagasse or waste material, is certainly not beyond the realm of possibility. The British, in East Africa, have carried out this practice in their plantations of sisal, a species with low hecogenin content, and are now producing cortisone from this source. An advantage in using *Agave* for the joint production of fiber and hecogenin in the United States is that marginal and submarginal lands could be utilized in areas of low rainfall.

Besides the more hardy species that might be used in southwestern United States are several species, such as *A. promontori* in Baja California, that meet the above specifications of a good fiber plus high hecogenin content and might be grown extensively in Mexico. It would take, however, a supreme effort as well as temporary sacrifices on the part of fiber producers in Mexico to replace with such species the traditional fiber plants, *A. fourcroydes* and *A. zapupe*, now grown in Mexico.

Dioscorea

By the end of 1954, introductions of *Dioscorea* had reached 636 collections. Of these, 402 were under various stages of cultivation, and 418 had been chemically analyzed. The remaining 218 collections not analyzed were being in-

FIG. 52 (Upper). *Dioscorea floribunda* Mart. & Gal. Plants grown without supports at Brooksville, Fla. Note the difference between the robust upright Mexican plants on the right (P.I. No. 201783) and the weak sprawling Guatemalan plants on the left (P.I. No. 200119), 1954.

FIG. 53 (Lower). *Dioscorea floribunda* Mart. & Gal. (P.I. No. 200119). Rhizome and portion of vine after two year's growth in the field at Brooksville, Florida, 1954.

FIG. 54 (Upper). *Dioscorea floribunda* Mart & Gal. (P.I. No. 201783). Rhizomes after two year's growth in the field at Brooksville, Fla., 1954.

FIG. 55 (Lower). *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783). Two-year-old rhizomes harvested at Brooksville, Fla., in 1954.

FIG. 56. Monroe Trieman and helper with basket and bag of harvested *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783) two-year-old rhizomes at Brooksville, Fla., in 1954.

creased under cultivation to obtain ample material for analysis.

Over a period of two years, ending in March, 1954, nearly 50,000 plants of high-yielding *Dioscorea* collections were propagated and distributed from Glenn Dale for field testing. Among these were two especially high-yielding collections of *D. floribunda* from Guatemala (P.I. No. 200119) (Fig. 22) and Mexico (P.I. No. 201783). At present, about six acres of high-yielding *Dioscorea* are under cultivation. Various cultural tests involving fertilizing, supports, spacing of plants, hardiness and other factors have been or are still in progress.

Besides the plantings at the Section's Plant Introduction Gardens near Savannah, Georgia, and Coconut Grove, Florida, as well as at the Federal Experiment Station in Mayaguez, Puerto Rico, others were also established in the southern States at Mercedes, Texas, in cooperation with the Texas Research Foundation, and at Baton Rouge, Louisiana, in cooperation with the Horticultural Research Department of Louisiana State University. In addition, several plantings were made under an informal agreement with Merck and Company at the following locations: Weslaco, Texas, in cooperation with the Texas Agricultural Experiment Station, Substation 15; Brooksville, Florida, in cooperation with Monroe W. Treiman; Clewiston, Florida, in cooperation with the United States Sugar Corporation; Albany, Georgia, at the Merck and Company Flint River Plant.

Although, in time, all phases of horticultural practices are to be considered, the first two seasons, 1953–1954, of trial plantings were primarily to find out whether the rhizomes of these plants were cold-hardy when left in the ground over winter or whether they could withstand drought conditions in mid-summer, as well as where the best growth could be obtained. This was the basis for selecting these areas for field testing.

The first field plantings were made in March, 1953, at which time about 35,000 plants were distributed to the locations. Two field observations and evaluations of results obtained have been made thus far—the first in October–November, 1953, and the second in November, 1954. An examination of the first-year field trials at the end of the growing season revealed that the plantings at Savannah, as well as those at Brooksville and Baton Rouge, produced the best results. The Clewiston plantings were a failure because of the high water table, and the Albany plantings did not receive proper attention; both were discontinued and the remnants harvested and shipped to the Savannah Station. The plantings at Coconut Grove are to be increased because of favorable results obtained there.

Although tubers of *Dioscorea floribunda* will attain sufficient size from seedlings in nine to 15 months (Fig. 35) for shipment from our Glenn Dale greenhouses, the first plants placed in the field in 1953 were 20 months old and averaged about 15 grams in weight and ten inches in length (Fig. 36). From this relatively small beginning some tubers were produced after growth of one year in the field that weighed 14½ ounces (cf. Fig. 49) and after two years growth, 1.8 lbs. (cf. Fig. 51).

Savannah, Georgia. Several factors determined our decision to concentrate horticultural studies on *Dioscorea* at the Section's Barbour Lathrop Plant Introduction Garden near Savannah, Georgia. First, Mr. David Bisset, Superintendent, had a long experience in growing and storing the edible *D. alata* that could be applied to the present problems. Also, the light sandy loam is excellent for the growth and cultivation of dioscoreas, and the warm temperate

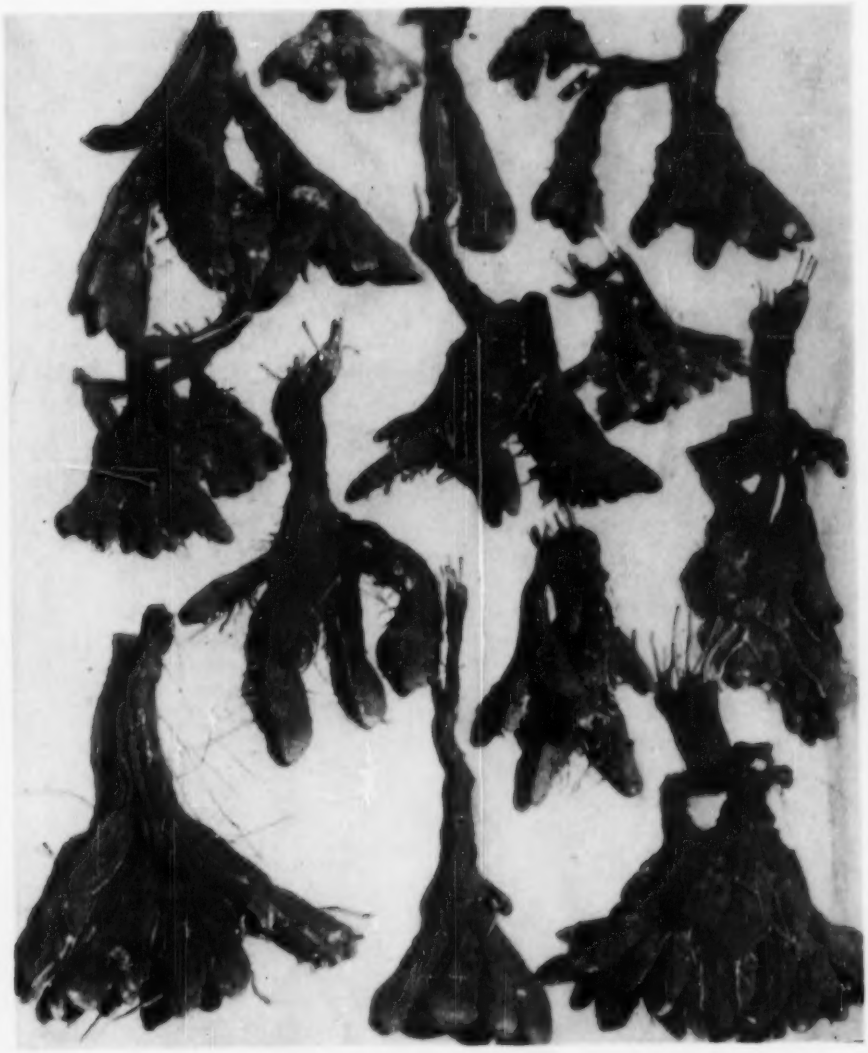


FIG. 57. *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783). Rhizomes after one year's growth in the field at our Plant Introduction Garden, Coconut Grove, Fla. A good example of the "pata de mula" type of rhizome, 1954. About × ¼.

FIG. 58. *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783). Rhizomes after one year's growth in the field at Baton Rouge, La., 1953. About $\times \frac{1}{4}$.

climate of the region permits a rather long frost-free growing season. Hence, not only are high-yielding dioscoreas grown here but representatives of all the collections are to be maintained at Savannah for possible future breeding and selection work.

In order to determine optimum locations for the growth of *Dioscorea*, two diverse plantings were made at Savannah: one in a cleared area of less than half an acre in an old open pine woodland; another of about half an acre in an open field. The plants were somewhat hilled when first set out, but heavy rains in the summer of 1953 more or less leveled the ground. The soil in both locations was sandy loam and had been fertilized. The rows were four feet apart with about one foot between plants in the rows. All of the plants were given supports of bamboo branches upon which the vines could climb (Fig. 48). Growth in both locations was approximately the same, and the amount of rhizomes produced averaged only slightly higher in the plants grown in the woodland. Rhizomes weighing between nine and 14.5 ounces were obtained, with the average weight for all rhizomes slightly below six ounces. Some of the plants were to be harvested and stored for replanting in the spring of 1954, while the remainder were to be hilled and left in the ground over winter.

FIG. 59. Julian C. Miller examining plants of *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783) growing on wire supports at Baton Rouge, La., 1954.

In consideration of the fact that all of the planting stock shipped to the field from the Glenn Dale greenhouses was only about twice the size of the plants shown in Fig. 35 and averaged about 14 grams each in weight, and that the tops were removed before shipment, the above results were not discouraging for the first-year growth (Fig. 49). Also, it was

necessary for the small rhizome to become well-established before growth could begin.

In November, 1954, the Savannah plantings were again examined. The 1954 growing season had been far below that of an average normal year; rainfall was only 50% of normal and water for irrigation had been limited. In spite of heavy irrigation of some of the plots, the plants on the whole had not made the growth expected. Individual plants in some of the plots were most robust, leafy and vigorous in general than the rest, denoting that selections for such types should be undertaken along with some experiments in breeding.

Maize had been planted and interspersed with *Dioscorea* plants in one plot to determine its possible use as a support for the vines. This experiment was not successful, primarily because the maize was planted too late in the season. This experiment was repeated in 1955, with the maize planted much earlier. In another control plot the vines were left unsupported, but the most successful growth was made where bamboo stalks were used as supports.

The most encouraging results were from Guatemalan plants of *D. floribunda* (P.I. No. 200119) (Figs. 50 and 51) harvested at the end of the 1953 growing season and replanted in an open field with bamboo supports in the early spring of 1954. One of these harvested plants weighed 1.8 pounds, while three plants weighed a total of 3.75 pounds. The rhizome weighing 1.8 pounds after two seasons growth is the largest yet produced under cultivation in our program.

Brooksville, Florida. Because of their long experience in the growing of edible dioscoreas for market, an arrangement was made with Monroe W. Treiman and his mother to grow about an acre of high-yielding plants at their farm near Brooksville, Florida, during the 1953 season. This plot was doubled for the 1954 season.

The plants at Brooksville were grown somewhat hilled up, similarly to sweet potatoes, in rows four feet apart with about one foot between plants in the rows. The plot had been lightly fertilized. The plants were allowed to grow on the ground without support. Although only about 60% of the Guatemalan *D. floribunda* survived and showed, on the whole, rather poor growth, the Mexican *D. floribunda* (P.I. No. 201783) (Fig. 52) established itself almost 90 percent and the top growth was rather vigorous. A few plants were dug; the largest rhizomes of the Guatemalan plants weighed seven ounces, whereas the largest in the Mexican material weighed only three-and-one-half ounces. The plants were left in the ground for another year.

In 1954, mortality continued high in the weak-stemmed prostrate Guatemalan material, although rhizome development (Fig. 53) had increased considerably in those plants that still survived.

The Mexican plants appeared in excellent condition (Fig. 54). Early in 1954, since spring is apparently the best time for harvesting and replanting rhizomes left over winter in the ground, two 100-foot rows of this material were dug and the rhizomes divided sufficiently to plant ten additional rows of the same length. Some well-rotted manure was added to this plot of ten rows. Several of the plants dug in this plot showed exceedingly good growth for one season. In several instances rhizomes of one-half pound weight were obtained. The Treimans were of the opinion that if the rhizomes were left in the ground until early spring and were then harvested, the large lower part of them could be used for drug production and the neck

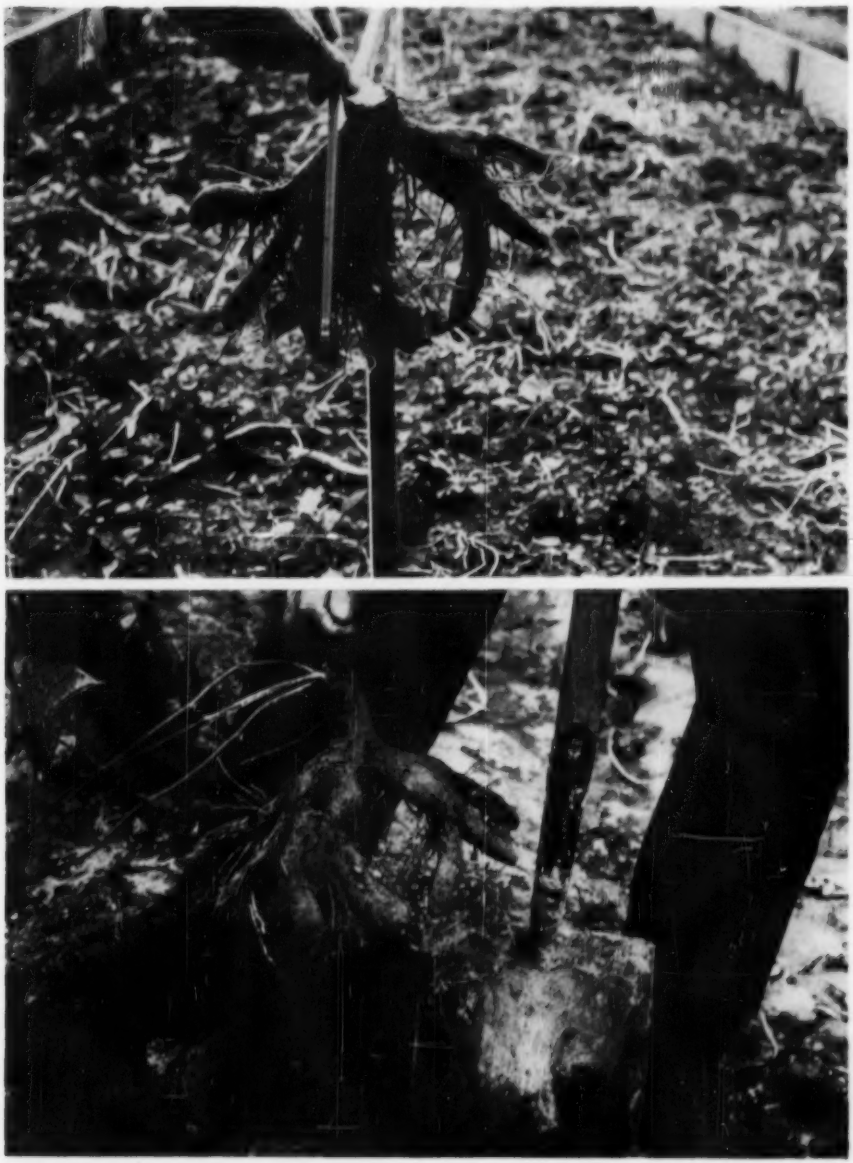
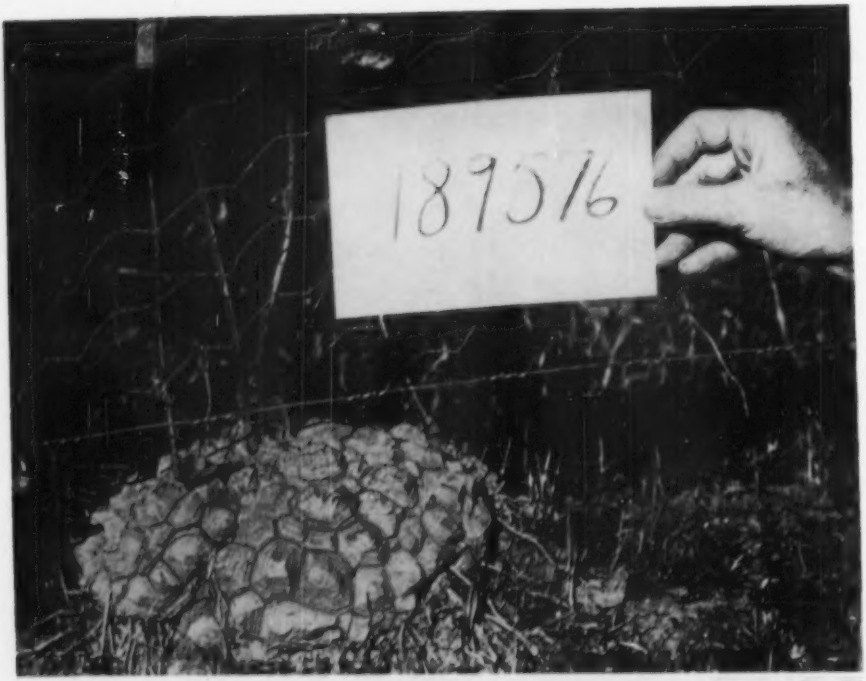


FIG. 60 (Upper). *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783). Rhizome after two year's growth in the field at Baton Rouge, La., 1954.

FIG. 61 (Lower). *Dioscorea floribunda* Mart. & Gal. (P.I. No. 201783). Rhizome (with stems and leaves attached) after two year's growth in the field at Baton Rouge, La., 1954.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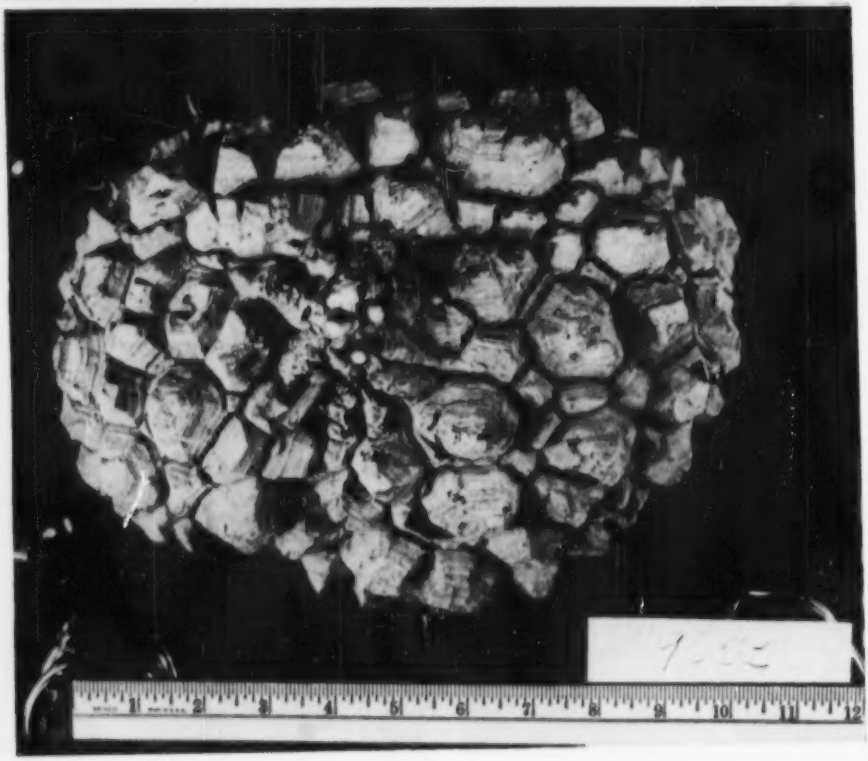

(crown) or upper part for immediate replants. The latter, as shown by the above, contain enough nutriment to cause quick and rapid growth. It was anticipated that by the end of the 1955 growing season these rhizomes might attain an average of more than one pound per plant.

In November, 1954, approximately 190 plants of the Mexican *D. floribunda* were dug (Fig. 55) from the plots planted two years previously with propagules from Glenn Dale. These plants, which had been left in the ground over winter, were harvested, and 85 lbs. of rhizomes were obtained, minus the necks which had been removed and used for replanting (Fig. 56). The average weight was about one-half pound per plant. Some parts of the rhizomes might have been left in the ground accidentally, since a laborer dug them and the brittle rhizomes usually ramify in several directions.

Coconut Grove, Florida. On January 13, 1955, tubers of three lots of *Dioscorea* were taken from every fourth hill in the row from an acre planting made on March 18, 1954. These were cleaned and weighed (Fig. 57). From 80 hills of the Mexican *D. floribunda*, 38.3 lbs. of tubers were harvested, averaging 7.9 oz. each. The largest tuber weighed 1.3 lbs. This was the largest one-year-old rhizome and first-year growth obtained anywhere in the southern States.

Baton Rouge, Louisiana. The plants at Baton Rouge, Louisiana, had also been hilled up as are sweet potatoes, and were provided wire supports. The rows were about five feet apart with plants one-and-one-half feet apart in the rows. The deep furrow between the rows allowed ample irrigation. All of the plants were making rather consistently good growth. Immediately after the plants were set in the field in the spring of 1953, all the tops died back, and for about two months very little growth was evident. Nevertheless, the luxuriant top growth and rhizomes finally produced corresponded favorably to that obtained at Savannah (Fig. 58). The plot had been fertilized and cultivated, and was maintained in excellent condition. The plants were to be left in the field over winter. In the fall of 1954, after a second-year growth under the above conditions, one of the rhizomes harvested weighed 1.25 lbs. (Figs. 59, 60 and 61). The work at Baton Rouge is under the supervision of Julian C. Miller.

Texas. The plantings at Mercedes and Weslaco, Texas, were drastically affected by the prolonged drought and high salt content of the little available water used for irrigation. In a letter written in October, 1953, W. R. Crowley, Superintendent at Weslaco, wrote: "Only one line, that of P.I. No. 201783 (*D. floribunda*), survived the disastrous drouth that prevailed in this area during the first eight months of this year. We managed to establish a fair percentage of the plants with limited water supplies early last spring. This south Texas area was without significant rainfall and there was no water available for irrigation from the Rio Grande river for several months. By early June, the mortality was high in the planting, especially in some lines. At the time the drouth was broken by rains late in August, only plants of the one line remained alive".

In spite of the climatic difficulties encountered during the 1953 growing season, it was decided to continue the plantings at least another year. However, although *D. floribunda* proved to be gen-

FIG. 62 (Upper). *Dioscorea mexicana* Guillem. (P.I. No. 189576). Plant after two year's growth in the field at the U. S. Federal Experiment Station, Mayagues, P. R., 1954.

FIG. 63 (Lower). *Dioscorea mexicana* Guillem. (P.I. No. 189576). Close-up of above two-year-old 7-pound rootstock to show the polygonal corky bark. (Photo: W. C. Kennard).

erally cold-hardy when left in the ground over winter, results were not better in 1954 and loss of plants continued high. The remaining plants were harvested and shipped to Savannah for winter storage and field planting in the spring of 1955. This concluded, for the present, our field tests in Texas.

If conditions become such that dioscoreas are replanted in the Mercedes-Weslaco region of Texas, September, in the opinion of R. H. Cintron, would be the best time to make plantings. If planted at this season of the year the plants would be able to make some growth and establish themselves. They would then go into dormancy, and if they were susceptible to the light frost and freezing usually occurring in this region, damage would thereby be averted. In the spring they would be ready for prompt and steady growth. Harvest could then be made in the fall after one full-year growth. This method would avoid taking a complete growing season to establish the plants.

Puerto Rico. Studies have been initiated at the Federal Experiment Station, Mayaguez, under the supervision of W. C. Kennard, to determine the effect of several methods of vine support (poles and chicken wire, poles only, living castorbean plants, and no supports), of two spacing distances (two and three feet between plants in rows five feet apart), and of time of harvest on growth, tuber yield and diosgenin-content of a high-yielding selection of *D. floribunda* (P.I. No. 201783).

After one year the most satisfactory vine support was found to consist of poles and chicken wire. Vines growing on this type of support yielded the greatest weight of tubers. A support of poles alone was fairly satisfactory, but it is considered that increased yield would probably justify the extra expense of placing wire between the poles. As evidenced by poor vine growth and low tuber yield, *D. floribunda* cannot be grown satisfactorily without supports of some kind, but living castorbean plants are not suitable. Significant yield differences did not occur between the two spacing distances for any of the types of support.

Most of the *Dioscorea* selections growing at Mayaguez do very well. For instance, a plant of the Mexican "cabeza de negro" (*D. mexicana*) produced a rhizome in two years that weighed seven pounds (Figs. 62 and 63). After two years growth all the rhizomes of *D. floribunda* averaged about three pounds, with some weighing almost four pounds.

CONCLUSIONS REGARDING *DIOSCOREA*

Since the evidence, thus far, shows that *Dioscorea* is the most abundant source of a cortisone precursor and the most practical plant to handle from a cultural point of view, we are presenting here our conclusions. Cultivation of the edible true yams, namely, *D. alata* L., *D. cayenensis* Lam., *D. esculenta* (Lour.) Burkill, *D. latifolia* Benth., *D. rotundata* Poir. and *D. trifida* L.f., has been studied, and miscellaneous publications, including several by our own Department of Agriculture, have been issued on the subject (42, 43, 47). Although the basic methods of cultivation recommended in these papers can be applied to the wild species, a difference in specific needs is to be expected because of the greater number of species involved, the variety of habitats from which they have come, and the great variation in type of their rootstocks, many examples of which are illustrated in this paper.

Our findings in cultural investigations during the past two growing seasons have been very similar to those obtained from the cultivation of edible dioscoreas. The plants gave the best results when cultivated in a deep, mellow, somewhat sandy loam, although, when well-drained, heavier soils also gave good results. No elaborate preparations of

the soil were made other than deep ploughing. There is no doubt that if much well-rotted manure and vegetable matter were added to the soil, a greater growth of rhizome would result. Application of a complete fertilizer at the rate of two to two-and-one-half ounces per plant shortly after the plants appear above ground and again six or eight weeks later will aid materially in producing better top growth and larger rhizomes.

Experiments are now in progress involving the use of ground limestone. Such experiments concerning pH values of the soil for optimum growth are most essential. This is particularly true since many of the high yielding collections are found in nature among limestone in neutral to somewhat basic soils.

If possible, all cultivated plants of *Dioscorea* should be provided with some support upon which the vines can climb. In every case where support was provided the plants showed lower mortality and greater tuber yield. Because of the labor and other costs in providing supports, however, this may be prohibitive in the production of a crop. A particular disadvantage that often results when yams are grown on clean-cultivated ground without supports is that in the early part of the season the tips of the young vines are injured by the heat of the surface soil, and growth is retarded.

The problem of finding an economical and practical support is still unsolved. Our tests, as noted above, thus far show that greater rhizome production is obtained when the plants are given a support than when they are left unsupported. Since artificial supports, such as bamboo branches and poles and wire, not only entail the cost of the supporting materials and the use of expensive hand labor but also interfere with cultivation of the plants, a living natural support appears to be the only logical solution.

The ideal support would be a leguminous plant that would not only support the plants but would also help build up the soil. To this end, Merck and Company has been experimenting with species of *Crotalaria* in its Guatemala *Dioscorea* plantings. Use of dwarf castorbeans (*Ricinus communis* L.), with the thought of producing a complementary crop, proved unsuccessful in our plantings at the Mayaguez Federal Experiment Station, Puerto Rico. Maize, which from a nutritional standpoint is not so good, has not yet been given a fair trial.

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Hard Fibres[1]

These fibres, obtained from the leaves of agaves, Manila hemp, New Zealand flax and various bromeliads, are important in the manufacture of cordage and of coarse textiles.

W. BALLY AND F. TOBLER

Hard Fibres in World Economy

"Hard fibres" is the term applied most widely to the leaf or structural fibres derived from tropical and subtropical plants, and mainly used for cordage or for mats, sacking and suchlike textiles. Until the end of the eighteenth century, "soft" (bast or stem) fibres like flax and hemp were the most important raw material used by rope makers, and it was in the early nineteenth century only that fibre from agaves, Manila hemp (abaca), New Zealand flax and other monocotyledonous plants began to be used instead.

"Hard" fibres is a misnomer in so far as the textile fibres included in the term are not harder than the "soft" types, though thicker and stiffer. Whereas cotton and the stem fibres consist almost exclusively of cellulose, a number of other compounds enter into the chemical composition of hard fibres (Table I). Moreover, the arrangement of the fibres as seen in cross section differs in the leaves of monocotyledons from that in the stems of dicotyledons, and hence the methods of fibre extraction are different.

Agave, Manila hemp and New Zealand flax have their natural homes in widely separated areas. Long before the arrival of Europeans, cordage and mats were made by the natives, in Mexico from agave fibres, on the Philippines from abaca and in New Zealand from *Phormium tenax*. As in so many other instances, these attainments of ancient aboriginal civilizations have been developed by the white peoples and made available to the world. Attempts to cultivate the hard fibre plants outside their original habitats have been attended with little success in the case of abaca and *Phormium*, while the agaves, particularly sisal, have conquered new territories, in Africa and tropical Asia.

Even before the last war, world production of agave fibre and Manila hemp amounted to 525,000 tons annually, of which 188,000 tons represented abaca, 226,000 tons sisal (*Agave sisalana*) and 110,000 tons henequen (*Agave fourcroydes*). Yields of abaca on the Philippines and of sisal in Indonesia went down considerably during the war. Since then the shortage of Philippine abaca has only in small part been made good by new areas of cultivation in the Americas. In contrast with this, sisal production in East Africa has increased by one third, and extensive plantings have in recent years been made in Mozambique, Brazil and Haiti. The second World War thus brought about an important shifting of cultivation centres: South East Asia, which, before 1939, accounted for half the world supplies of hard fibre, now produces only a quarter.

Since 1946, hard fibre production has again been on the increase. According to the figures published by the Bureau of Agricultural Economics in Washington and the British Commonwealth Economics Committee, the world supply of

[1] Adapted from Ciba Review 99. 1953.

agave fibres and Manila hemp, in 1951, totalled no less than 521,000 tons, viz., 288,000 tons of sisal, 128,000 tons of abaca and 105,000 tons of henequen. But as these quantities barely satisfy demand, efforts are made everywhere towards obtaining material from other fibre plants, e.g., the Bromeliaceae in Brazil and the Argentine, and various kinds of yucca (beargrass) in the Gulf States. Leaf fibres from several Bromeliaceae (pineapple family) have yielded good results in Central and South America, so that there is some prospect of obtaining a raw material competitive with sisal in both usefulness and price.

TABLE I

CHEMICAL COMPOSITION OF THE FIBRES OF SISAL, MANILA HEMP AND NEW ZEALAND FLAX, EXPRESSED IN PERCENTAGES OF WEIGHT AND CALCULATED ON THE SAME WATER CONTENT. (*After A. J. Turner*)

	Cellulose	Hemi-cellulose	Pectin	Lignin	Water-soluble Substances	Oils and Waxes	Content of Water
Sisal (*Agave sisalana*)	65.8%	12.0%	0.8%	9.9%	1.2%	0.3%	10.0%
Manila hemp (*Musa textilis*)	63.2%	19.6%	0.5%	5.1%	1.4%	0.2%	10.0%
New Zealand flax (*Phormium tenax*)	45.1%	30.1%	0.7%	11.2%	2.2%	0.7%	10.0%

To the many problems besetting the world trade in hard fibres a new one has been added: how will the rapid development of synthetic fibres affect the market? Synthetic fibres no doubt have the advantage of lighter weight, greater strength and immunity to rotting, as well as being produced from materials easily available. Productive capacity in synthetic fibres, however, is too small as yet to present a real threat to the natural hard fibres. Even if the former should become important competitors, it is still conceivable that the hard fibres might fill a gap in other fields where there is a lack of raw material.

Agaves

Botany. In most botanical works the genus *Agave* is classed as a member of the Amaryllidaceae. However, certain characters have led an English botanist, J. Hutchinson, to establish a special family, that of the Agavaceae, in which he also includes *Phormium tenax*, the New Zealand flax or hemp.

In Central America, where it is indigenous, the genus *Agave* is represented by many, not easily distinguishable species. At an early period plants were brought to Europe where they spread rapidly, particularly in the Mediterranean countries. The typical large leaf-rosette of the century plant (*A. americana*), with its immense flowering stem rising from the centre, has become so characteristic a feature of tourist centres such as Monte Carlo that many painters commit the anachronism of portraying it in Mediterranean scenery of classical times.

All species of agaves have some characters in common. The fleshy, longish or lanceolate leaves end in a sharp point and usually bear spines on their margins. They form a rosette which for the first few years rests on the ground. During many years new leaves are regularly formed which are arranged in a spiral. In sisal (*A. sisalana*) the leaves may attain lengths of from two to five feet. With progressing age and with the consecutive formation of a stem, the lower leaves begin to die off unless, as in cultivated plants, they are previously cut away. Older specimens thus bear their

leaf-rosette at the top of a stem of varying height.

Young leaves assume first a vertical, but in course of time a more or less horizontal position. During its lifetime a sisal plant produces an average of 300 leaves, a fairly constant number, varying little or not at all under the influence of environmental factors. On the other hand, the length of the leaves is strongly influenced by soil and climate, and this is of great importance for sisal planters; indeed, leaves must be at least 18 inches long to be of use in fibre production, the price of the fibres being determined by their length.

The fibres obtained from the leaves constitute longitudinal bundles composed of fibre cells which are characterized by much thickened cell walls. In the cross section of the leaf, the bundles close to the surface appear as independent groups, while those more in the centre form sheaths around the vascular bundles which are distributed throughout the whole section. In the course of processing, the xylem (wood) and phloem (bark) parts of the vascular bundles become decomposed, so that most of the commercial fibres are crescent-shaped in cross section. The fibres deriving from the sheaths may attain considerable lengths: in sisal, about 4 ft. 6 in.; in cantala, 3 ft. 8 in.; and in henequen, 3 ft. 6 in.; the width varying between 0.2 mm. and 0.4 mm. Single fibre cells from the centre of the leaf attain lengths of from 1 mm. to 2.3 mm. in *Agave americana*, 1.5 mm. to 2.5 mm. in cantala, and 2.7 mm. to 4.4 mm. in sisal. The properties of fibres from young leaves are different from those of older ones. Lignified old fibres are more difficult to spin, but being thicker they are also stronger.

The root system is characterized by numerous slender roots which spread chiefly horizontally in the top layers of the ground down to a depth of two and a half feet. Consequently sisal derives its nutrients mainly from the uppermost layers of the soil.

Inflorescences appear very late and attain heights of seven feet or more. After flowering the plant dies. Contrary to most cultivated plants, favourable environmental conditions will promote an early formation of inflorescences in agaves. In Mediterranean regions they flower after ten to 15 years, in greenhouses sometimes only after fifty. In East Africa and Indonesia, on the other hand, sisal often throws up the flowerstalk after a mere five or six years, while the species on the henequen plantations in Yucatan is said to flower much later.

The ramified panicle bears a large number of pale yellow, tubular flowers, two or three centimetres long, with three sepals and three petals from which six stamens and the pistil protrude. Ripe seeds are seldom produced in the inferior ovary, and propagation by seed is therefore out of the question. Reproduction is nevertheless ensured in two ways so that planting material is always ample. Firstly, buds appearing in the axils of the panicle grow into small plants, known as bulbils, which root easily. As soon as the bulbils are fully developed the mother plant dies. Secondly, long before the plant flowers, the root stock produces suckers which grow horizontally and form shoots at their apical end, when about three feet long.

The sterility of agaves may be partly explained by the fact that the cultivated forms are probably complicated hybrids. Nevertheless, recent experiments in East Africa and Brazil have been successful in forcing sisal plants to produce seed.

FIG. 1 (*Upper*). Sisal plantation in East Africa. Bulbils produced in the tall inflorescences at this stage are used for propagation.

FIG. 2 (*Lower*). A sisal nursery in East Africa. (*Photo: Maxim, Nairobi, Kenya*).

This was done by severely cutting back the flower stalks before ramification took place, whereupon lower branchings produced blossoms and later capsules with viable seed. Although of no practical use at present, these experiments may be significant for the future, as they provide a means of obtaining generative progenies and of crossing the various species and varieties.

The genus *Agave* comprises 250 to 300 species which have been described by A. Berger and W. Trelease. In 1933 H. Ross established no less than 62 species for Mexico alone, most of which are used for fibre production but only in very restricted areas. It is not always easy to determine a species because diagnoses are usually based on floral characters and flowers appear only after several years, seldom on wild plants. The agaves of importance in hard fibre production are all classed in the subgenus Euagave, group rigida.

Agave cantala Roxb., the maguey plant, forms a short stem and produces numerous suckers. Its leaves end in a sharp point and have many spines on the margins. From Mexico, its native country, the species found its way to the East at an early period, probably through the intermediary of the Spaniards. It was recorded in Indonesia by Rumphius in the seventeenth century and is still cultivated there as well as in the Philippines and India.

Agave fourcroydes Lemaire has a stem up to four feet high. The bluish-green leaves end in a sharp point and have marginal spines half an inch long. It is the most important fibre plant of Mexico to-day and yields what is commercially known as "henequen".

Agave sisalana Perrine, the true or white sisal, shows the following characters, clearly distinguishable also in non-flowering specimens. Able to form a stem, sisal gives rise to many suckers, and possesses coarse fleshy leaves of green or bluish-green hue, with very few, if any, spines on the margins. The latter point is of importance to cultivators, as spiny leaves render cutting operations troublesome. The term "sisal" recalls the port of the same name in Yucatan from which the first sisal fibres were exported. In 1836 the American Perrine took sisal to Florida, from where it was transplanted to Africa and Indonesia.

Of the many Mexican agaves whose fibres are marketed under various names, only a few shall be mentioned here. The zapupe agaves are cultivated in northern Veracruz and some areas of central Mexico (*A. Deweyana* Trel., *A. zapupe* Trel., and *A. Lespinassei* Trel.). Probably *A. amaniensis* Nowell et Trel. also belongs here. It was first noticed in the botanical garden of Amani (Tanganyika). This long-leaved variety, which seemed to hold great promise when discovered in 1933, is almost certainly of Mexican origin, although it cannot be identified with any of the known species. An agave known only in El Salvador (*A. letonae* F. W. Taylor) is locally important for the manufacture of marine cordage and coffee bags. In western Mexico fibres are also derived from the Mezcal agaves (*A. tequilana* Weber, *A. pseudotequilana* Trel., *A. palmaris* Trel., and *A. pes-mulae* Trel.) which are used for brewing pulque, a favourite local drink. Tula istle (*A. lechequilla* Torr.), one of the plants yielding istle fibre, grows wild in northern Mexico and in Texas. Istle plants native to the Mexican plateau are *A. lopantha* Schiede and *A. funkiana* Koch et Bouché (juama istle). Of the same family and closely related to *Agave* is the genus *Fourcraea* (after the French chemist Foureroy), the most important species of which, *F. gigantea* Vent., yields Mauritius hemp. Its origin is unknown. In Mauritius the plant and the fibre are known as "aloe", in Brazil as

"piteira" and "pita", respectively. Other species of *Fourcraea* occur in the West Indies and in South America.

As in other plant genera difficult to classify, recent studies of cell nuclei, especially of the number of chromosomes occurring during division, have shed much light on the origin of cultivated species. The most important of these appear to be polyploid, i.e., the number of their chromosomes is a multiple of the somatic number of 30 chromosomes occurring in all wild species. Various investigations of sisal and henequen agaves have yielded numbers from 137 to 149, so they probably should be considered pentaploids, whereas for cantala the clearly triploid number of 90 was found. Therefore, the cultivated agaves are in all probability crossings of various wild species, and this may explain their sterility.

FIG. 3. *Agave fourcroydes*, the source of fibre commercially known as "henequen", growing in stony ground, San Antonio, Yucatan, Mexico. (*Photo: F. Tobler*).

Cultivation. Of the cultivated plants in Mexico which caught the attention of the Spaniards soon after the Conquest, agaves were among the foremost. As early as 1528, Pater Motolinia gave a description of them. He used the Aztec word "metl", or the word "maguey", still current to-day, and referred to the distilling of pulque, a fermented drink derived from the sap of agaves. The same juice also yielded sugar and vinegar. According to Motolinia, the natives used agave fibres to make sewing thread, twine, cords, straps, harness and even clothes and shoes. The intact leaves served as roof covering and for building water pipes.

Some years ago, O. Richter was able to confirm from an examination of ancient paper specimens that the Aztecs actually made paper from agave fibres as mentioned by Motolinia. Agave paper was reserved for special documents, while the paper in common use was prepared from the bark of a ficus plant.

Soon after the conquest of Mexico the first agaves reached Spain. Charles de Lécluse (1526 to 1609) saw several plants in a monastery near Valencia, about 1550, and had a number of suckers sent to an apothecary, named Coudebecque, at Antwerp. In 1583 a flowering specimen of *Agave americana*, with its prodigious inflorescence, caused a great sensation at Pisa.

The fibres obtained in Italy and Spain from *Agave americana* were known as "zambara" or, in earlier works, as "zappara". Georg Rudolph Böhme gave a description of them in 1794 and mentioned that stockings, gloves, cloths and lace from "zappara" could be dyed very satisfactorily. In spite of this, the importance of the century plant as a source of fibre remained negligible compared with cantala which at an early date reached the Philippine Islands via India and was grown there and in Java on a large scale.

In its native country of Mexico, henequen (*A. fourcroydes*) is cultivated chiefly in Yucatan, minor culture areas being found in Campeche, Tamaulipas, Sinaloa and Chiapas. When travelling by rail from the port of Progreso to Merida, the largest section planted to henequen is traversed, formed by row on mile-long row of this most vital native product thriving on stony ground. The name "henequen" refers both to the plant and the fibre.

Of all the agaves, sisal has attained the greatest importance as a cultivated plant, the fact that its leaves are devoid, or nearly devoid, of marginal spines proving one of numerous points in its favour. Dr. R. Hindorf was the pioneer of sisal cultivation in Africa. In 1892 he suggested that sisal be transplanted to German East Africa, as it then was. After the first shipment of young plants had arrived, in 1893, cultivation immediately prospered, so that at the outbreak of World War I, 62,000 acres (25,000 ha.) were planted to sisal, the fibre shipped amounting to thirty percent of the total exports from the colony. More plants were later imported, chiefly to take the place of Mauritius hemp (*Fourcraea gigantea*) which had proved a failure. In 1951 the value of sisal fibre exported from Tanganyika reached 23,363,000 pounds sterling, or sixty-two percent of the total exports. Total production in that territory for the first four months of 1953 was 50,543 tons as against 49,839 tons for the same period of 1952. Both in Africa (Tanganyika, Kenya, Mozambique) and in Indonesia and Brazil—the major sisal-growing countries—the estate system has become the established form of cultivation. Large sums are invested not only in the holdings but also in expensive decorticating plants. The field work is considerably facilitated by the fact that agaves propagate through bulbils or suckers exclusively. Nor have diseases and plant pests been prominent so far.

Strangely enough, *Agave sisalana*, though indigenous to almost rainless Yucatan and in habit a typical xerophyte adapted to a dry climate, also grows well in regions with considerable precipitation and even produces a greater amount of fibre. In Yucatan the mean annual temperature is 78° F., with very little seasonal variation; the relative humidity of the air is between 73 and 89 percent, and the yearly amount of rainfall varies between 29½ in. and 51½ in. In East Africa conditions are similar. But sisal does equally well in Indonesia, where the amount of rainfall is between 78 and 120 in. In contrast with Sumatra, the Java holdings are in districts with marked periods of rain and drought.

In East Africa, Indonesia and Brazil it has been proved that *Agave sisalana* will grow in the poorest soils, though of course giving poor yields. Typical deficiency diseases occur if the soil is

wanting in potash. According to the observations of E. C. J. Mohr, a Dutch expert in soil investigation, deep soils are needed in the first place, particularly in a dry climate. The most suitable soils are alluvial lavas coming from volcanic regions, and, indeed, in Java and parts of Sumatra the sisal plantations are situated in large plains overtopped by volcanoes. In Tanganyika, on the other hand, sisal is planted on weathered gneiss, in Haiti on neozoic sediments and in Yucatan on coral limestone. Everywhere the presence of a sufficient amount of potash, calcium, magnesium, phosphorus and nitrogen is a basic requirement if the sisal cultures are to thrive.

The simplest method of fertilizing the plantings consists in returning the waste material from the decorticators to the fields. The fibre content of the leaves being no more than four percent, huge quantities of waste are available, for which a number of uses have been suggested. Flooding the fields with the waste water from the factories yielded striking results in Java, and the practice seems to have proved its worth also in East Africa. The effect of various artificial fertilizers on the growth of the leaves and fibres and on the onset of inflorescence has been tested in experimental stations, but only one useful finding emerged: potash fertilizer will eliminate certain deficiency diseases.

In siting a new agave plantation, conditions other than those of soil must also be taken into account, e.g., a sufficient supply of water for the factory, suitability for laying out a field railway, availability of labour.

Planting is done either with suckers or bulbils. Both have advantages and disadvantages: at the moment of planting out, the shoots are more advanced but differ much in size and development, while bulbils are more uniform. Both suckers and bulbils—the latter should be taken from late flowering parent stock—are first raised in nursery beds.

FIG. 4. Cross sections of a sisal (upper) and a henequen (lower) fibre, showing the thick-walled fibre cells which compose the fibres. ×410.

Before planting into the open field, conditions as favourable as circumstances will permit should be created: surplus rain must be allowed to drain off into ditches. In many areas, the planting of a cover crop of leguminous plants, which store nitrogen, is recommended.

The spacing of the plants has been the subject of much controversy. Comparative field trials in East Africa have shown that the number of leaves formed per acre is increased and the weight of

FIG. 5. Cutting sisal leaves in British East Africa. (*East African Photographs Services*).

individual leaves reduced in close plantations, while inflorescence is retarded, so that a greater yield of fibre results per acre and cycle (a cycle being the time from the first cut to the clearing of the field). In view of the tillage and harvesting operations a minimum distance of about ten feet between the rows is indicated. At this rate, with about two-foot intervals between plants in the same row, about 2250 plants will come to the acre. Under these conditions the average lifetime of a plant is from seven to eight and a half years, whereas in a field planted with 1214 plants to the acre, inflorescence will take place within six years. Double rows are frequently laid out, too.

Another much discussed problem is the treatment of the soil. In the tropics only regular weeding will prevent plantations from being overrun by dangerous growths which greatly reduce yields. On the other hand, bare soils are impoverished by rapid weathering and, if there is the slightest incline, by leaching, most of the humus being washed away. Covered soils have the advantage of retarding inflorescence. It is thus advisable to plant the ground with cover crops, preferably leguminous types. According to experiments performed at Mlingano (Tanganyika), clean weeding is indicated during the first years in order to keep down the obnoxious plants and ensure a satisfactory yield of leaves; later,

leguminosae should be planted, serving as cover crops.

The time for cutting any leaf is normally determined by the angle it forms with the stem. The youngest leaves, which envelop the vegetation point, rise almost vertically, but during their growth they spread out gradually until they have attained an almost horizontal position. In Indonesia, leaves forming an angle of 45 degrees are considered ripe for cutting. There and in East Africa sisal is first cut about two and a half or three years, henequen in Yucatan four or five years, after planting. Machetes of various forms are used in the various countries to sever the leaves from the stem near the ground, and care is taken not to damage the remaining leaves. The spines having been removed, the leaves are cut to the length required for the decorticator, and bundled.

Breeding. Frequent attempts have

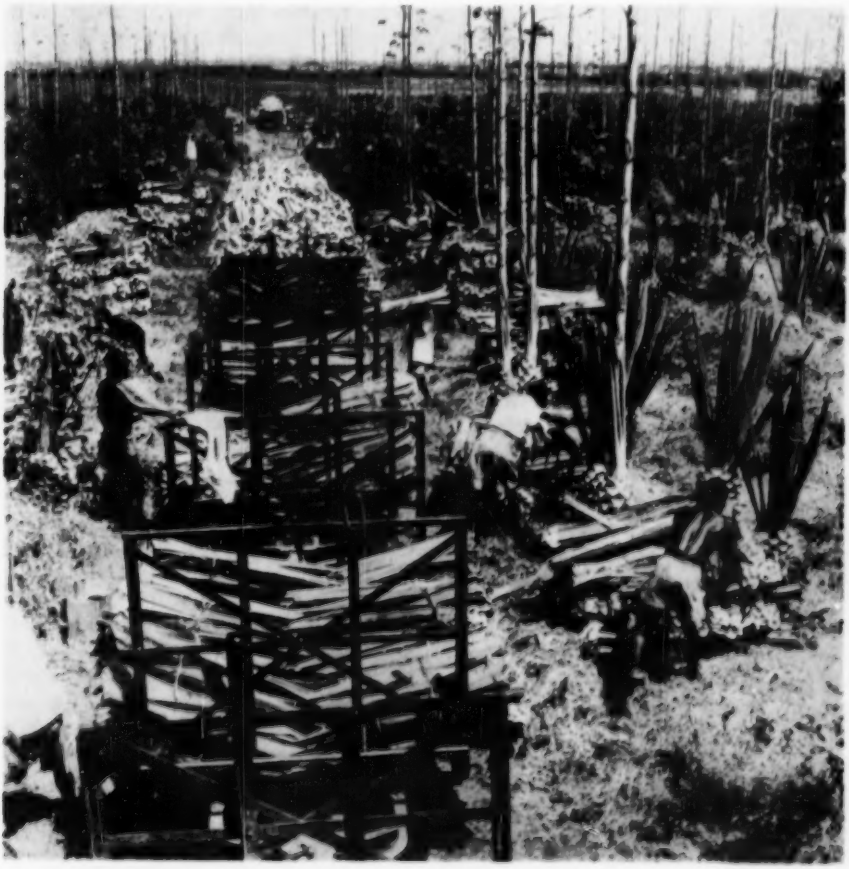


FIG. 6. Loading bundles of cut leaves on a sisal plantation in East Africa. (*East African Photographs Services*).

been made to improve *Agave sisalana* by breeding. As the actual sisal clones are propagated by vegetative means exclusively, such attempts would seem to be doomed from the start. However, judging from certain observations, some improvement seems possible, since occasional cases of bud mutation have been recorded. On the other hand, sisal plants whose inflorescence is cut back will bear seed, and the flowers may be used for pollination with pollen from other varieties. Crossing the large-leaved *Agave amaniensis* with *Agave angustifolia*, for instance, has yielded a promising progeny. The future will show whether improvements of a lasting nature can be brought about by such methods.

Abaca or Manila Hemp

In the town of Davao on Mindanao, the main centre of Philippine abaca culture, natives from the neighbouring rural districts may often be seen dressed in hand-woven clothes made from abaca fibre supplied by *Musa textilis*, a banana plant.

The first account of this Philippine fibre, dating from the year 1686, was published by William Dampier, the English navigator who stayed on Mindanao for several years. It was more fully described by the naturalist Georg Eberhard Rumphius (1627–1702) in his "Herbarium Amboinense" (Amsterdam, 1741–55) as occurring on Mindanao and on Sangir island, north of Celebes. These wild plants, he says, always had an owner who guarded them jealously, nobody being allowed to cut such a tree without his permission. He further tells that the natives of these islands wove the fibres obtained from *Musa textilis* into two kinds of cloth, both known as "koffo" and of a natural whitish colour somewhat like unbleached linen. The coarse kind was dyed black, red and yellow, the fine and glossy type left white or painted with designs of many different flowers and figures. According to Rumphius, anchor cables and sacking were also made from the fibre.

Exportation of abaca was not attempted before the nineteenth century and reached its peak towards the eighteen-fifties.

The name "Manila hemp", generally used for the plant and fibre, is a double misnomer. Abaca has nothing to do with true hemp and, though native to the Philippines, is not grown near Manila. To-day, therefore, its native name "abaca" (stress on first syllable in English) is gaining steadily in acceptance.

Abaca (*Musa textilis* Née) and the various species of banana together form one of the foremost genera of the Musaceae family. According to E. E. Cheesman, an English botanist, perhaps by no means all the cultivated and wild "Manila hemp" plants of the Philippines belong to the species *Musa textilis* as established by Née in 1801 on the basis of some characters of no systematical value. However, all plants cultivated under that name in botanical gardens or elsewhere outside the Philippines seem to belong to the species *Musa textilis*, such as retained and more accurately defined by Cheesman.

Abaca is a herbaceous plant reaching a height of eight to ten feet with a diameter at the base of between 16 and 20 inches. From the spreading root stock shoots arise which eventually assume the form of false stems built up of a number of tightly packed, overlapping leaf-sheaths. Sixteen to 20 inches broad and five to seven feet long, the leaf-blades expand at the top of the false stem. At the time of flower-ripeness, the inflorescence emerges from the hollow stem, presenting a long axis with many unisexual flowers in the axils of green or purple bracts. The fruits are thickish, two or three inches long, and, unlike the edible banana, contain small black viable seeds.

The fibre bananas are generally smaller than the edible, the stems are thinner and of a darker green, and the leaves narrower and more pointed. Many transitional forms, however, occur in nature, as hybrids are frequent. The fibre bundles are arranged within the sheaths of *Musa* much as in agave leaf-blades. They lie closest on the underside of the sheath, which is turned outwards. The outermost and oldest sheaths yield brown and coarse, the innermost white and very fine, fibres. Abaca fibre bundles range in length from six to 12 feet and in diameter from about 1/125 to 1/25 inch, the single fibre cells ranging in length from one-eighth to one-half inch and in width from 16 μ to 32 μ. The abaca fibre excels all other plant fibres in tensile strength. The breaking strain per grammeter of abaca fibres may extend from 40,000 to 75,000 gm., while it ranges between 35,000 gm. and 55,000 gm. for sisal, and is less for any other fibre used for cordage. Another great advantage apart from its lightness, is its resistance to water, salt water in particular. Hence for over 100 years abaca has been in great demand for marine uses.

Before the war, abaca was produced in the Philippines in two distinct areas working on completely different economic lines. On Leyte and Samar, in southern Luzon and on the many islets lying between Luzon and Mindanao, small holdings which applied primitive methods of cultivation and processing were the rule. In the south, on the other hand, i.e., in the neighbourhood of Davao on Mindanao, there developed a modern plantation industry, first under American, and later mainly under Japanese, management, which accounted for 54 percent of the total harvest and became a formidable competitor of the north. During and after the war, however, the Japanese plantations were abandoned, the ground cleared partly for growing food plants and partly left fallow. In the north the situation has changed little. NAFCO (National Abaca and Other Fibres Corporation), founded in 1946, endeavours to restore production to its pre-war level. However, in view of the enormous demand for the fibre, plantations of abaca were established, many years ago, in other tropical countries as well, particularly Indonesia. After the close of the war, the U. S. Department of Agriculture successfully started abaca cultivation in Panama, Costa Rica, Honduras and Guatemala with suckers from the Philippines. To-day the abaca production of Central America is beginning to play a significant part on the world market.

FIG. 7. Young Mexican sorting dried sisal fibres. (*Photo: Three Lions, New York*).

As the abaca plant requires special climatic and soil conditions, its cultivation will always be limited to a few specific regions. A warm atmosphere and intense humidity uniformly distributed throughout the year best meet the requirements of this truly tropical plant. In countries with distinct dry seasons, irrigation will make up to some extent

for the lack of water. In the abaca-growing parts of the Philippines, the annual rainfall ranges from 70.8 to 110.2 inches, and the annual temperature means vary between 78° and 80°F. Another capital factor for successful cultivation of abaca is deep fertile soil of loose texture, well moistened but affording good drainage. To protect the young plants from wind, leguminous trees are occasionally interplanted, which also serve to enrich the ground with nitrogen.

New plantings are made from rhizomes or from suckers while seeds are only exceptionally employed, as initial growth of seedlings is slow. On Indonesian estates, rhizomes are almost exclusively used, since they are easily transported and root quickly, but the parent plant yielding the rhizomes has to be sacrificed. This may be avoided by planting suckers as is customary on the Philippines.

Filipinos plant the suckers in unprepared ground in double or single rows, eight to ten feet apart, permitting 500 to 600 plants to the acre. Later on, the fields are regularly hoed or ploughed. Batatas, maize or leguminous cover crops are grown between the rows. Occasionally, coconut or rubber trees are raised jointly with abaca.

Every abaca harvest produced by a field deprives its soil of a substantial amount of nutrients, depleting it thoroughly within ten to 15 years. Some of the fertility is restored to the ground if the waste leaf-blades are dug in again immediately after cutting the stems. Fertilizing with potash has brought the best results so far, and favourable effects were noted in fields covered with ash during a volcanic eruption.

As soon as the large inflorescence emerges, the time for harvesting has come. The false stalks are generally cut when they are two or three years old, as by then a number of suckers have developed which will themselves be ready for cutting two or three years later. Harvesting requires skill, for some stems are thick, others thin, and young shoots must not be damaged in the cutting. The cuts are applied just above the ground and obliquely in order to allow running off of rain water and to protect the root stock from rotting. The outermost sheaths yield only low-quality fibres, those lying further in, brownish or streaky, and the innermost sheaths, pure white fibres. So as to facilitate stripping, the sheaths are cut on the spot to the length required by the machines, usually five feet. Sorting of the sheaths and subsequent operations are carried out either in the field or in the decorticating centres.

Like all banana plants, abaca is subject to attack by a number of diseases, sometimes with devastating results. Young plants, for instance, may be killed by a wilting disease presumably caused by a *Fusarium* fungus. Bunchy top disease, manifested by shrub-like growth of the stools and stunted narrow leaves, is traced to a virus transmitted by a plant-louse, *Pentalonia nigronervosa*. Another virus disease, transmitted by the plant-lice *Rophalosiphum nymphae* and *Aphis gossypi*, is mosaic characterized by dark green and yellow spots on the leaves. Control of these diseases is best achieved by preventing infection; affected stools should therefore be removed immediately and burnt. Heavily infected fields should not bear *Musa* crops for several years. Fortunately there has been some success in breeding resistant varieties.

Even before the second World War, experiments were carried out in the Cameroons to make use of the fibres of edible bananas such as *Musa paradisiaca* L. and *Musa sapientum* L. As only the fresh-grown portions of stalk were extracted and with the least possible delay, these plants produced a fibre in

no way inferior to good-quality abaca. Should exploitation of edible banana species prove economically worth-while, the growing demand for abaca type fibres could easily be met, and even extended, thanks to their many uses.

New Zealand Flax

Phormium tenax yielded one of the most important fibres of New Zealand's native population, the Maori. The first description of the plant and its textile

FIG. 8. Sisal bulbils, partly with roots, after falling from flower stalks and suitable for use as propagating material. (*From L. H. Dewey*).

uses is found in Captain James Cook's "A Voyage to the South Pole and Round the World", London, 1777.

The genus *Phormium* belongs to the family Liliaceae. New Zealand flax has a creeping rootstock which sends up numerous shoots. Each of these forms a fan-shaped cluster of up to eight closely packed leaves. Yellowish or bluish-green, they are folded lengthwise along the midrib and are about two feet long, one to four inches broad and often split at the tip. Eventually a long inflorescence rises from the centre of the cluster, on which many waxy red flowers arranged in panicles appear during the summer months (November to January). As the stamens mature before the ovary, pollination in the same flower is not possible. Cross pollination takes place by means of insects, honeybirds or the wind. In a single inflorescence as many as 100 capsules may ripen, containing 60 to 150 seeds each.

Two species of *Phormium* are found in New Zealand, viz. *P. tenax* and *P. colensoi*. The latter is known as "mountain flax" and has little commercial value, owing to the weakness of its fibres. However, being resistant against certain diseases, it is very useful for breeding purposes. Unlike *P. colensoi*, *P. tenax* possesses stiff upright leaves and panicles.

The distribution of fibre cells in the cross section of *P. tenax* offers a similar picture to that in agaves and *Musa textilis*. They either form sheaths around

the vascular bundles or occur as individual strands. In his work on the mechanical principle in the anatomic structure of monocotyledons (Das mechanische Prinzip im anatomischen Bau der Monokotylen, 1874), the Swiss botanist Simon Schwendener (1829–1919) used this very plant to demonstrate that the mechanical elements, i.e., the fibre complexes, form I-shaped girders connecting the upper with the lower surface of the leaf. This significant distribution of structural parts gives the leaves a very high degree of bending strength.

Phormium tenax grows spontaneously throughout New Zealand and on the Norfolk Islands to the northwest. The Maori also transplanted it to the Auckland Islands in the south. The densest populations are found in the Manawatu valley of North Island. The plant grows in many types of soil up to levels of 4,000 feet, and thrives with an annual rainfall of 20 inches as well as with one of 145 inches. *Phormium* is, however, critically dependent on the water table. For many years all the relevant geographical, ecological and economic problems were investigated on "Moutoa Estate", a public domain situated on the borders of the Manawatu River. Starting from the observation that with a given water table, *Phormium* stools were the prevailing plants within the natural communities, successful attempts were made to create similarly favourable conditions, or so-called "induced Phormium swamps", by draining plots that were too moist. Later, however, the drained top soil caved in, becoming flooded again so that marsh plants like reed-mace and sedge gradually displaced *Phormium* completely.

The Maori did not grow *Phormium*. They exploited the natural resources which are still considerable. Cultivation is at present restricted to three big plantations, Moutoa Estate being the largest. Only a small part of its 5,000 acres, though, is cultivated, the bulk comprising natural stands and "induced swamps".

Planting by rhizomes has proved the only practical method, at the same time guaranteeing the genetic purity of the new stock. Generally five or six years will elapse before the first satisfactory crop of leaves can be brought in. As all the leaves must be cut, another four or five years will pass before the remaining stools have produced enough new leaves worth harvesting in their turn.

FIG. 9. Abaca-producing regions and ports of export shipment in the Philippine Islands. (*After J. E. Spencer*).

Cultivation of *Phormium* is not therefore an interesting proposition for the small farmer, and did not become popular in New Zealand.

Planting rhizome fragments is done in rows, between August and November, after the soil has been ploughed and cleaned of weeds. The rows are laid out about eight feet, the stools four feet apart. During the first few months regular weeding is necessary to promote the growth of the young stools. Within five years a stool produces about 30 leaves, but the harvest at the first cut is rather less, some leaves dying off every year. Annual cuts would never pay, as the stools would suffer too much and piece-wages are very high. The leaves are cut with a sickle-shaped knife six to eight inches above ground level, laid in bundles and transported on field railways. Normally the amount of fibre per acre is about one ton, but crops of five tons have been gathered.

In the stripping mills the leaves are stripped by passing between a beater bar and a quickly revolving drum. Compared with hand stripping the fibres thus obtained are somewhat weaker, and the waste must be worked over once more as it still contains a considerable percentage of fibre. The fibres are then treated in washing machines, plaited into strands and bleached on the fields. Subsequently they are moved by conveyor belt to a scutching drum, in which revolving hammers remove all remaining tissues and short fibres. This process corresponds to the scutching of hemp and flax. Finally the fibres are hanked and pressed into bales.

Exports of New Zealand flax rose steeply from 1831 to 1907, increasing from 1062 to 28,547 long tons. After the first World War, however, production and export figures dropped rapidly, presumably owing to the competition of sisal and abaca. In 1942 the last shipload of 26 long tons left New Zealand.

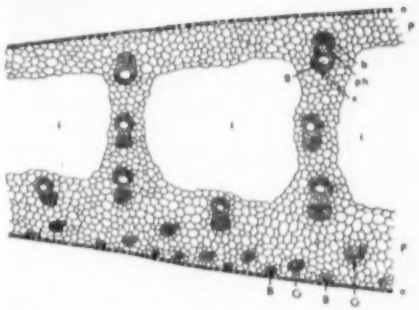


FIG. 10. Part of cross section through a leaf-sheath of *Musa textilis*, showing: o = epidermis; ii = air-containing intercellular spaces in the mesophyll (P); B = isolated fibre bundles; G = reduced vascular bundles; b = fibre bundle forming a crescent-shaped sheath around the vascular bundle; ph = part of the phloem with sieve tubes; x = xylem with large vessels (g) and a crescent-shaped fibre bundle which is turned outward. ×25. (*After J. von Wiesner*).

On the home market, however, *Phormium* has assumed increasing importance since 1930 for the textile and cordage industries which from 1946 to 1947 processed 5400 long tons of fibre.

Small quantities of phormium are produced outside New Zealand, notably on St. Helena (3000 long tons), in Kenya, Tanganyika, Natal, South Africa, Mexico, Brazil, Chile and the Argentine. In recent years great efforts have been made in Brazil to spread and improve *Phormium* culture. The many drawbacks of *Phormium*—long periods between cuts, comparatively small yields, marked susceptibility to the moisture content of the soil, and irregular employment of labour—will be compensated only if the fibre is of a quality able to compete with sisal and abaca, or if it has a market in a local textile or cordage industry.

Bromeliaceous Fibres

The pineapple family (Bromeliaceae) comprises stemless plants with long rigid leaves growing rosette-like from a cen-

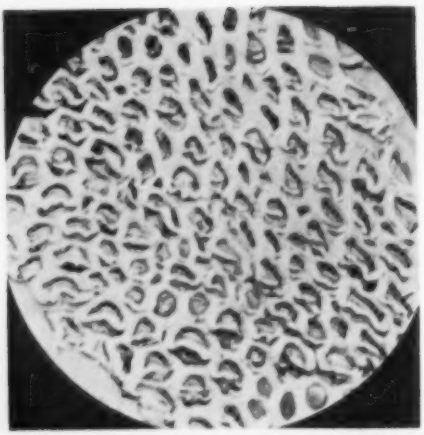


FIG. 11. Cross section through an abaca fibre bundle. ×400. (*Dyes Laboratories of Ciba Limited, Basle*).

tral base. In the tropical and subtropical regions of South America, their original home, they grow in the forks of trees or on dry, often rocky ground. Several species have been transplanted to other continents, e.g., *Ananas sativus*, the pineapple plant proper, which has an edible collective fruit and is now widespread in southeast Asia, Oceania and South Africa.

The stiff and usually spiny leaves contain strong fibrous matter which from old has been used as a textile material, particularly in Indonesia where the natives have used the fine fibre (pineapple fibre) together with the finest abaca or true silk to make sheer cloths for veils and other purposes.

The fibre bundles, as seen in cross section of the leaf, are similarly arranged as those in agaves or phormium, the vascular bundles near the underside of the leaves showing a thick layer of phloem fibres. Sometimes it is merely the phloem fibre groups which give the leaves their characteristic stiffness. Scraping off the underside of the leaves is sufficient to produce fairly good fibres which must be thoroughly washed and, if necessary, separated so as to be ready for spinning. These threads, fine and strong as they often may be, are little suited to industrial exploitation. The exceptional fineness of the phloem fibres is explained by the fact that they are not lignified, but the commercial fibre bundles also show admixtures of rather coarse particles of the vascular bundles.

Much better results are to be had with the sturdier fibres—rather jute-like in their final state—obtained from the vigorous and often imposing members of the family which constitute an important part of the flora of subtropical South America. In the northern Argentine and in Brazil in particular, there flourish several species of the genera *Bromelia* and *Neoglaziovia*. In Brazil these grow largely in the arid almost treeless coastal regions. In the Argentine, on the other hand, the spreading rosettes of several species cover wide areas in dry forests with trees of medium height, forming almost impenetrable thickets owing to their quick propagation by stolons.

According to P. Corrêa, the two most important kinds of Brazilian fibre are derived from, first, "gravata de gancho", also called "caraguata", "gravata de raosa, croa, croata" (English "silk grass") and, second, "gravata de rede". Their respective scientific names are *Bromelia karatas* L. and *Ananas bracteatus* Schult. Both form terrestrial rosettes and have radical narrow spiny leaves eight feet two inches long and about two inches wide. The fibres of these plants, some of which have been known for over a century, are exceedingly fine and, notably in the case of *Ananas bracteatus*, have great strength. That is why the natives use them to make nets. Although they are exported by Brazil, their cultivation has never been considered in view of the enormous wild-growing stocks. Moreover "gravata de gancho" was frequently mis-

taken for "gravata de rede". The latter is not seen as frequently as other terrestrial Bromeliaceae, but is fairly common on the coast as far north as Pernambuco and particularly in Rio de Janeiro, occurring also in the States of Rio Grande do Sul, Matto Grosso, Minas Geraes and in Paraguay. The prolific "gravata de gancho" has a much wider distribution and yields 60–70 tons of leaves per hectare, from which there amount of waste pulp is far smaller in Bromeliaceae and the proportionate output of fibre greater (fibre yield 6%). The less complicated stripping devices are not unlike those used for abaca on the Philippines. Harvesting is more troublesome than with abaca, especially where the leaves are very spiny so that gloves have to be worn. Stripping is done from the base of the leaves and yields strands of fibres about five feet

FIG. 12. Flowering specimen of *Bromelia Hieronymi* Mez. in the Chaco of Salta, Argentina. (*Photo: C. A. Luna Ercilla*).

may be extracted some 8800 to 11,000 lb. of fibre.

Together with the above-mentioned two plants, *Neoglaziovia variegata* Mez., known as "caroa" or "croa", to-day apparently yields the bulk of the processed Bromeliaceae fibres exported from Brazil. Owing to the great similarity of the various technical fibres, however, it is practically impossible to state the exact botanical origin in each particular case.

As compared with agave leaves, the long, which are largely free from other tissues. After drying in the air and sun, the last remaining particles of leaf tissue drop off, leaving the fibres white or cream in colour, with their tensile strength unimpaired. They are, therefore, a welcome substitute for agave and musa fibres. It is generally stated that caroa fibres are three times as strong as jute fibres and much finer. They are rich in cellulose. Many products can be obtained, among them rope, light rope, twine, cordage, fishing nets, burlap, can-

vas, rugs, carpets, fine papers, and fabrics for clothing that may be mixed with cotton. Sacks made of Brazilian fibre are 50% lighter than those made of jute.

In recent years considerable amounts of processed fibre have gone to the United States for twine and sacking. Latterly the exploitation of fibres has made great strides in the Argentine, and it is from there that detailed information has been forthcoming on the various species concerned and their native names.

Botanists have described 1500 American species of Bromeliaceae, ten or twelve of which yield fibres. They are: in the Argentine, *Pseudananas macrodontes* ("ihvira" or "Pina del monte"), *Bromelia Hieronymi* ("chaguar blanco", "chaguar rosado", "cardo gancho", etc.), *Bromelia Balansae* ("caraguata"), *Deinacanthon Urbianum* ("chaguar salado", "chaguari"), *Dyckia chaguar* ("chaguar"), *Bromelia serra* ("chaguar morado", "caraguata"), *Bromelia laciniosa* ("caraguata"), *Aechmea distichantha* ("caraguata-ih", "caraguata-chusa", "cardo-chusa", etc.); in Jamaica, mostly *Bromelia Pinguin* (English, "wild pine"); and in Brazil, *Bromelia Binoti* and *Neoglaziovia variegata* ("caroa"). Other or the same species occur in Central America and Paraguay.

These Bromeliaceae generally grow in fairly open woods or in bush and pampas country. Their close investigation has been undertaken in the north of subtropical Argentina, where fibre production has been established on an industrial basis. According to C. A. Luna Ercilla, two firms are producing fibre from wild-growing material on a substantial scale, one at Santiago del Estero, the other at Pirané, Formosa Territory. The plants exploited are: *Bromelia Hieronymi, Pseudananas macrodontes, Bromelia Balansae* and *Bromelia serra*. Their fibres are equally suited for spinning and weaving, though no doubt exclusively used in the home market.

Machines of the "raspador" type should prove serviceable in the production of the fibre, but, to some extent, devices of South American construction have also come into use. They are mostly fitted with drums, like the older kind of raspador and with feeder belts which convey four to six leaves simultaneously. These decorticators are said to have a capacity of 700 to 1000 kg. of leaves per day. The fibres are washed at once and freed of any clinging pulp. Ripe leaves have a fibre content of 3.5 to 8.5 percent. *Bromelia Hieronymi*, which is in great favour among Argentine specialists, tops the list with regard to yield.

Extraction of Fibres

Extraction of fibre from the leaves of agaves and abaca is in one respect simpler than the processing required by the stems of flax, hemp, jute and other plants yielding finer spinning material. Leaf fibres can be cleaned almost completely by machine, whereas even to-day many stem fibres are still retted previous to being processed. In the countries where the hard fibre plants are indigenous, the leaves were occasionally retted, it is true, but by now the natives have turned to mechanical means exclusively. The soft tissue is simply scraped off, this being the easier the fleshier the leaf. Primitive though it is, the method yields a good fibre; being coarser by nature, the leaf fibres are less apt to suffer damage than their more delicate counterparts, the bast fibres.

Sisal and Other Agave Fibres. At an early period, the Europeans introduced machinery for the extraction of sisal and other agave fibres. In these machines the fibres are detached from the green leaf by crushing. In order to obtain a clean spinnable fibre, the material must be washed simultaneously with, or im-

mediately after, decortication. In the course of time the technique has been improved, and efforts to better it continue unceasingly.

The practice of stripping sisal and henequen leaves by some mechanical device originated in Yucatan, nearly 200 years ago. The oldest stripping machine was the "raspador", and leaves were fed into the scraping drum by hand. A latticed cylinder (bird cage) pressed them against a firm base, causing the juice and leaf pulp to drain off while the fibre emerged on the other side.

By fixing two drums on an axle and replacing the hand crank by a mechanical drive, the double raspador was developed. Usually the leaf is held at one end and introduced into the narrow slit-like space between the drum and a concave plate, the so-called "quadrant". After blunt knives have scraped off the pulp from that part of the leaf, it is turned and the remaining half similarly treated. Sometimes there is a device of chains or ropes holding the leaves firmly and conveying them to the knives. The drums are usually 12 to 15 inches broad and three feet in diameter. A modern machine, of the Krupp type, for instance, with two attendants, will crush 6,000 leaves in a ten-hour day, a double raspador of four or five HP twice as many.

The dry fibre obtained differs with the quality of the work and the type of leaf handled. The danger of inadvertently injuring the fibres in the decortication process is small with thick fleshy leaves, but a comparatively large proportion of other tissue still sticks to the fibre and has to be removed later. The raspador, therefore, is not indicated for all kinds of agave nor for every area of cultivation.

The more modern types of machine are constructed on the principle of the conveyor belt which takes the leaves, sorted according to size and laid on the belt crosswise, to the machine, while another belt carries the fibres away. A jet of water directed at the crushing drums provides a first cleaning. Every new construction aims at greater ease of machine feeding, saving of labour and care in the handling of the fibre. The brass blades or knives vary in form, and their pressure may be regulated to suit the thickness of the leaves, thus guaranteeing an even treatment. Nowadays there exist machines able to handle stems of not too fine a bast fibre as well as leaf stalks. Advantages of the new system of J. Hubert are the more accurate setting of its various machine parts and the possibility of dividing it into two components, one for stripping, the other for cleaning the fibres. The machine is easily transported and can be worked in the fields.

The corrosive constituents of the agave leaf may not only impair the ultimate strength of the fibre considerably but also attack the metal parts of the machine in greater or lesser degree, depending on the species. That is why certain machine parts are made of bronze, while the conveyor chains have been exchanged for sisal rope which can be replaced on the spot.

In spite of all improvements, the loss of fibre in the decortication of sisal and other agaves is considerable. According to J. G. Thieme, even Indonesian stripping mills, which work with the most up-to-date equipment, reckon with a loss of 12 to 15 percent. The same author estimates the average loss resulting in more primitive establishments at as much as 25 percent. For that reason engineers are intent both on developing decorticators that will cause the least possible damage to the fibres and on devising methods of subsequent microbiological or chemical extraction. In a system known as "dry cortication" (patented by C. L. Walsh and African Sisal Co.) the skin only is removed mechani-

cally in a preliminary process and the leaf pulp then crushed and rubbed. There is thus no loss as the fibres are not washed and their lengthwise arrangement not interfered with, but the method is very complicated.

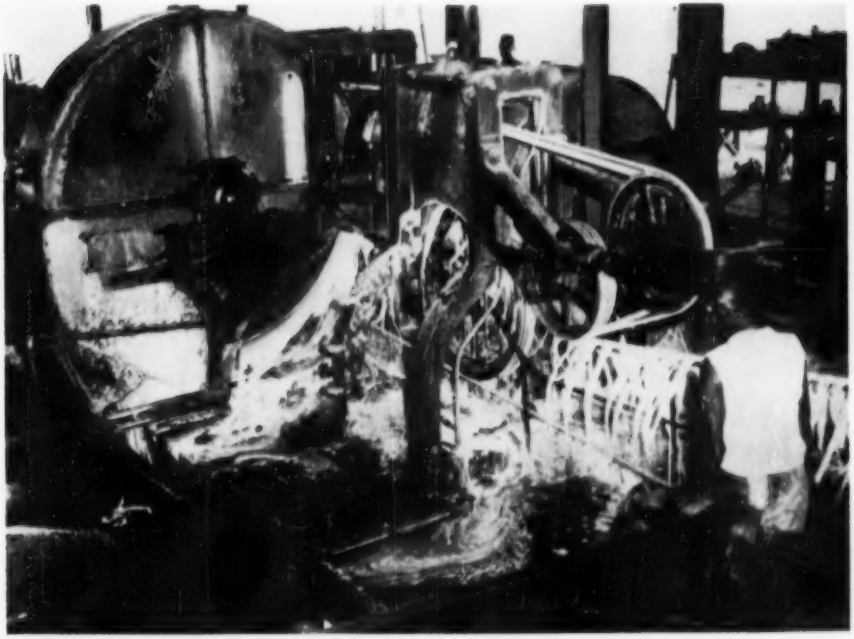
On emerging from the decorticator the damp fibres are usually cleaned by rinsing in water tanks and then dried in the open air on wires, ropes or cords. This process amounts to a preliminary bleaching of the fibre, that is, a form of processing indispensable in certain cases when increased resistance or some special use has to be considered. Exposure to the sun has no influence on the quality of the fibre and its colour, while rain may be detrimental. In order to obtain clean grades suitable for spinning, the dried fibre often used to be subjected to brushing, particularly in big establishments. Special brushing machines, similar to cards, strip off the dried tissue sticking to the fibre. However, as the clouds of dust produced by brushing were very harmful to the health of the operatives and damage to the fibre frequent, this method has largely been given up again. In recent practice the fibres, after passing through centrifugal washing machines, are progressively dried in a sequence of hot air chambers. This is effected mechanically by means of the "strip dryer" and, though a somewhat complicated method, has yielded excellent results in Indonesia.

The bagasse or waste remaining after removal of the sisal fibres amounts to many times their weight. For a long time, therefore, ways have been sought of turning the waste to some use. Interest focused on the cut fibres contained in the bagasse; like the tow from other textile fibres, they have some useful properties. They are obtained from the pulp by pressing, filtering and some kind of carding. According to Thieme's method, the whole mass is first retted in order to free the fibrous material. This "flume tow", as the waste fibres are called in East Africa, is mainly used for bags to ship coffee, groundnuts and other African commodities.

Owing to its content of potash, calcium and nitrogen, sisal refuse is well established as a fertilizer for exhausted soils. More recently other constituents, such as pectin, have been commercially exploited. The wax, of which there is a large amount in the superficial parts of the leaf, is also extracted. The sugar (six percent) may be turned into alcohol and power fuel, but only following dry cortication. Production of building panels from the fibrous elements of bagasse has also been considered.

In ageing plantations large quantities of dying agave stems have to be disposed of. The weight of a stem averages some 40 lb., that of a flower pole 10 lb. From 200,000 fresh stems (= 5000 tons dry weight) 1000 tons of low quality fibre may be extracted. These have been used, though with little success, in paper manufacture. The fibres of the flower pole, on the other hand, yield good packing paper, the cellulose in the raw material amounting to more than 50 percent. In view of its rich content in pectin, albumin, sugar, fatty acids and cellulose, attempts have been made to neutralize the leaf waste in order to produce a combustible gas containing methane and carbon dioxide, and suitable as a power fuel in the fibre-producing plants.

Abaca. As in the case of agaves, it is best to strip abaca immediately after harvesting the leaves, as the high percentage of tannic acid contained in the latter tends to discolour the fibres. Primitive methods of work have survived in many parts of the Philippine Islands. The Filipino sits down on the ground and takes an abaca stalk between his knees. With a sharp piece of bone, he peels off two to four strips, two or three inches wide, from the full length



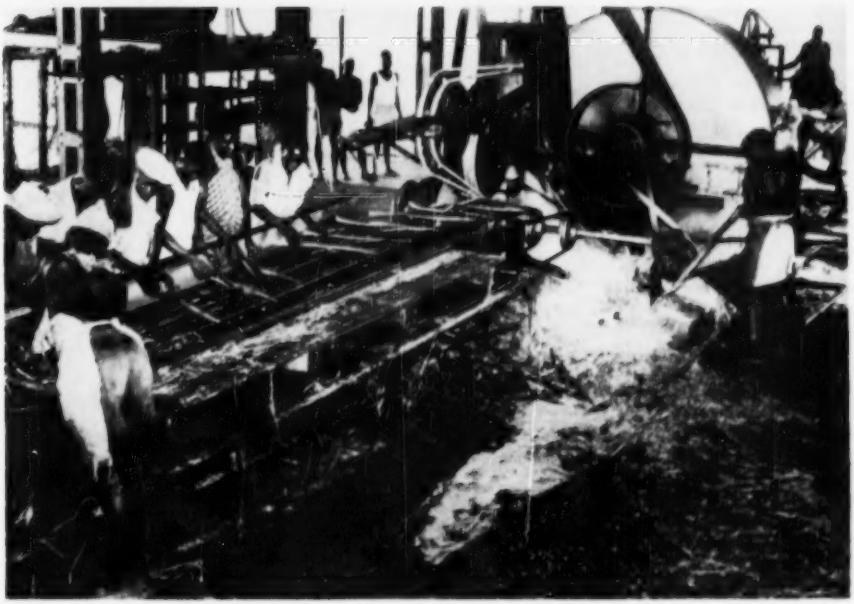


FIG. 13 (*Upper*). Mechanical treatment of sisal in a modern decorticator developed from the original "double raspador". Suspended on strings, the sisal fibres leave the machine while the plant juice and crushed pulp drain off into a tank. (*Photo: Mazim, Nairobi, Kenya*).

FIG. 14 (*Lower*). African workers laying sorted sisal leaves crosswise on the conveyor belt of a decorticator. (*Photo: Mazim, Nairobi, Kenya*).

of the sheath, removing the fleshy inner layer, which is thrown away as waste. Sorting the strips or tuxies according to colour and quality is of great importance for further processing. The next operation is carried out by means of a hand cleaning apparatus known as "jagutan" (hagotan) or "panguijan"; at one end of a horizontal pole fastened on uprights, one and a half to five feet above the ground, a smooth block of hardwood is fixed. Above this there is a knife, 12 inches long, with a handle of about 16 inches. By means of two bamboos, one of which is fastened to the knife, the other forming a foot-treadle, the worker can handle the knife in such a way that tuxies of any required thickness may be stripped off. He pulls the leaf gradually lengthwise through the apparatus, thus freeing all the fibre material in one movement. Hand-stripping is hard work and yields only small quantities of fibre; an output of 25 pounds of well cleaned fibre per man per day is considered exceptionally good.

Most stripping machines built on the raspador system have proved unsatisfactory for abaca. Automatic "decorticators", on the other hand, were successfully used by the Japanese. Mechanical devices are required to ensure high productivity and perfect cleaning of the fibre without impairing its strength, and should be easy to move to different sections of the plantation.

Since the technique of preparing abaca is very little developed as yet, fibres of widely different quality (now classed in groups) are placed on the market. The first group contains the cleanest fibres, and the best colour grades, which may be differentiated, according to the position of the original sheaths, the lightest fibres growing in the centre, the darkest and coarest fibres on the outside ("streaky 1–3" forming group one). Between the two are sheaths (about 10–15 percent) yielding yellowish fibres known as "midway". Light yellow to ivory coloured fibres are graded as "good current", still lighter ones as "superior current"; these are exported to Japan as "tagal" (material for hats). The fibres of the innermost sheaths are of particularly good quality, white, soft, though somewhat shorter. These "prime" and "extra prime" qualities are also made into tagal.

The fibres of the second group (good cleaning) are darker. They are also classed according to their origin from outer, medium and innermost sheaths. "Brown" with fairly soft, short fibres, often of dark colour, corresponds to "streaky 3", while "current" constitutes an important commercial quality of light brown fibres, soft and longer.

Fibres still less well and evenly cleaned belong to the third group which comprises the grades "good fair", "fair" and "medium". A fourth group has coarsely cleaned, rather brown fibres with straw-like properties.

Thus, in commercial grading, the original position of the sheaths on the stalk and the method of extraction are as important as is the degree of cleaning. A knowledge of the local origin is also relevant as practices vary from place to place.

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BOOK REVIEWS

A Dictionary of Terms in Pharmacognosy and Other Divisions of Economic Botany. George Macdonald Hocking. xxvi + 284 pages. Charles C. Thomas. 1955. $9.75.

The literature of economic botany has long been in need of a comprehensive encyclopedic dictionary, and this volume is the nearest approach toward fulfilling that deficiency that has so far been published. Prepared, as it has been, by a pharmacognosist, it is most thorough in its consideration of natural medicinal and pharmaceutical materials from the three kingdoms—animal, mineral, vegetable—but its coverage of other fields of plant utilization, while not so comprehensive, is sufficiently extensive so that the volume most assuredly is a long awaited contribution to the reference works on economically important plants in general. Timber trees, shade trees, weeds, fiber plants and other groups are not considered extensively, though within each of these categories some particularly important genera have received their merited attention. The categories not strictly medicinal or pharmaceutical, which are more systematically covered, include, among others, those of foodstuffs, condiments, beverages, sweetening products, masticatories, fumitories, aromatics, dyestuffs, tanning agents, toxic plants and animals, waxes and volatile oils.

In addition to the 250 pages devoted to definitions, there are ten appendices, five of them dealing with bibliographical material in various arrangements. Two of these five seem particularly valuable—one listing important serial publications in the field of pharmacognosy, the other listing periodicals devoted to particular economically important plants or plant products (chocolate, cinchona, citrus, coffee, cotton, ginseng, naval stores, olive, rice, rubber, soybean, spices, sugar, tea, tobacco, tung, wine). Of the other appendices, those appealing most to the present reviewer are concerned with the properties and therapeutic uses of drugs, with listing some 50 plant families and species yielding natural rubber, and with a "New Entries Supplement". Compiling a dictionary is a prodigious undertaking, for it involves not only years of bibliographical searching for and recording of words, expressions and definitions, but also the ever recurring problem of how best to present all the assembled data in the most accurate and acceptable manner consonant with the limitations imposed by publication costs. Various expedients must be adopted to achieve these ends, and those which have entered into the making of this dictionary are very adequately discussed in the explanatory foreword.

Materia Medica Vegetabilis. III. E. F. Steinmetz. Published by the author, Keizergracht 714, Amsterdam, Netherlands. 1955.

A review of the first two volumes of this work in ECONOMIC BOTANY, April–June, 1955, was critical of them because the lack of an index prevented anyone interested primarily in plants, instead of their pharmaceutical products, from finding information contained in them. This deficiency has been met by the appearance of an excellent index, divided into five parts and as many languages (Dutch, English, German, Latin, French), which now renders the other volumes of considerable reference value.